




"The InterPlanetary Internet a new way of thinking about deep space communications"



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Ed Greenberg
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InterPlanetary Network and Information Systems Directorate

*DESCANSO Seminar, JPL, Pasadena
19 July, 2001*



1. SUBMITTED BY NAME(S) AND SOCIAL SECURITY NO.(S)*		SECTION		EXT.	SUPERVISOR	RESIDENCE AND MAILING ADDRESS
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(4)						
S.S. NO.						
2. TITLE						
A SPACECRAFT BLOCK TELEMETRY SYSTEM COMPATIBLE WITH GROUND TRANSMISSION CIRCUITS.						
3. NOVEL FEATURES						
A system of telemetry formatting is proposed whereby spacecraft data are assembled into fixed-length, self-consistent blocks. Each block contains synchronization, a spacecraft measurement time reference, and a set of data associated with one source only. Formats are constructed by transmitting blocks from various sources serially. The block length is chosen to fit into the data content of a NASCOM ground block. Autonomous end-to-end block transmission is achieved which may significantly reduce ground processing complexity and cost.						
4. HISTORICAL DATA		DATE	LOCATION	5. NAMES OF PERSONS ACQUAINTED WITH ITEMS 4 THRU 7		
a. CONCEPTION BY INVENTOR	January 73	JPL	T. Gottlieb, 114-122			
b. DISCLOSURE TO OTHERS	April 73	JPL	W. Whitney, 198-229			
c. FIRST SKETCH OR DRAWING	N/A		J. Scull, 198-226			
d. FIRST WRITTEN DESCRIPTION	May 73	JPL				
e. COMPLETION OF MODEL OR FULL-SIZED DEVICE	N/A					
f. FIRST TEST OR OPERATION OF INVENTION	N/A					
6. RESULTS OF TEST						
N/A						
7. APPLICATIONS (INDUSTRIAL, GOVERNMENTAL, OTHERS)						
Achieves a simple end-to-end system design for any-remote telemetering system.						
8. REFERENCE REPORTS, PUBLICATIONS AND DRAWINGS						
IOM's 3645-73-104, 3645-74-106, 3645-74-223						
9. JPL CHARGE NO. UNDER WHICH THIS INNOVATION WAS DEVELOPED						
555-22633-0-3640						
10. SIGNATURES						
TECHNOLOGY UTILIZATION STAFF MEMBER	INVENTORS		DATE REPORTED			
(1) [Signature]			12-5-74			
APPROVED: TECHNOLOGY UTILIZATION MANAGER	(2) [Signature]		12-5-74			
	(3)					
	(4)					
*TO BE CONSIDERED AS A CO-INVENTOR ONE MUST HAVE CONTRIBUTED NEW AND NOVEL MATERIAL						

Final Transmittal Form for Scientific Reports, Vol. 1004-22, Nov 5, May 1974

May 1974

A Protocol for Packet Network Intercommunication

VINTON G. CERY AND ROBERT E. KATZ, MEMPHIS, TENN.

Abstract: A protocol that supposes the sharing of point-to-point packet switching networks to present a protocol for variation in individual network packet transmission rates, sequencing, flow control, end-to-end error detection, and the creation and destruction of logical process sessions. Some implementation issues are considered such as internetwork routing, accounting, and timing.

INTRODUCTION

IN THE LAST few years considerable effort has been expended in the design and implementation of packet switching networks [1] [7] [14] [17]. A major problem in developing such networks has been to share computer resources. A packet switching network includes a transportation mechanism for data between computers or between terminals. To make the data meaningful, terminals share a common protocol file, or upon conventions. Several protocols have been developed for this purpose [8] [12] [16]. These protocols have addressed only the problem of communication on the same network. In this paper a protocol design and philosophy that support resources that exist in different packet switching networks.

PACKET DATA
1978-05-31

PRELIMINARY DRAFT

A. J. HOOKE
MAY 15 1978

AEROSPACE DATA SYSTEMS STANDARDS

PART 3: TELEMETRY STANDARDS

STANDARD 3.3
SPACE DATA PACKETIZATION STANDARD

Prepared by
GSFC Data Systems Requirements Committee

Approved by:
Robert S. Cooper
Director

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland

A PROPOSED ASYNCHRONOUS MULTIPLEXED TELEMETRY SYSTEM FOR SPACEFLIGHT OPERATIONS

EDWARD P. GREENE

AUGUST 1977

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

In the beginning....

1970

1980

1990

2000

NASA Telemetry Standardization

*"Packet" Spacecraft
Telemetry and Telecommand*NASA/ESA
Working GroupBasic Space/Ground
Communications
Standards for
Space Missions

Consultative Committee for Space Data Systems (CCSDS)

Extension of
Standards for
More Complex
Space MissionsInternational
Space
StationExtension of the
Terrestrial Internet
into Space

Evolution of space standards



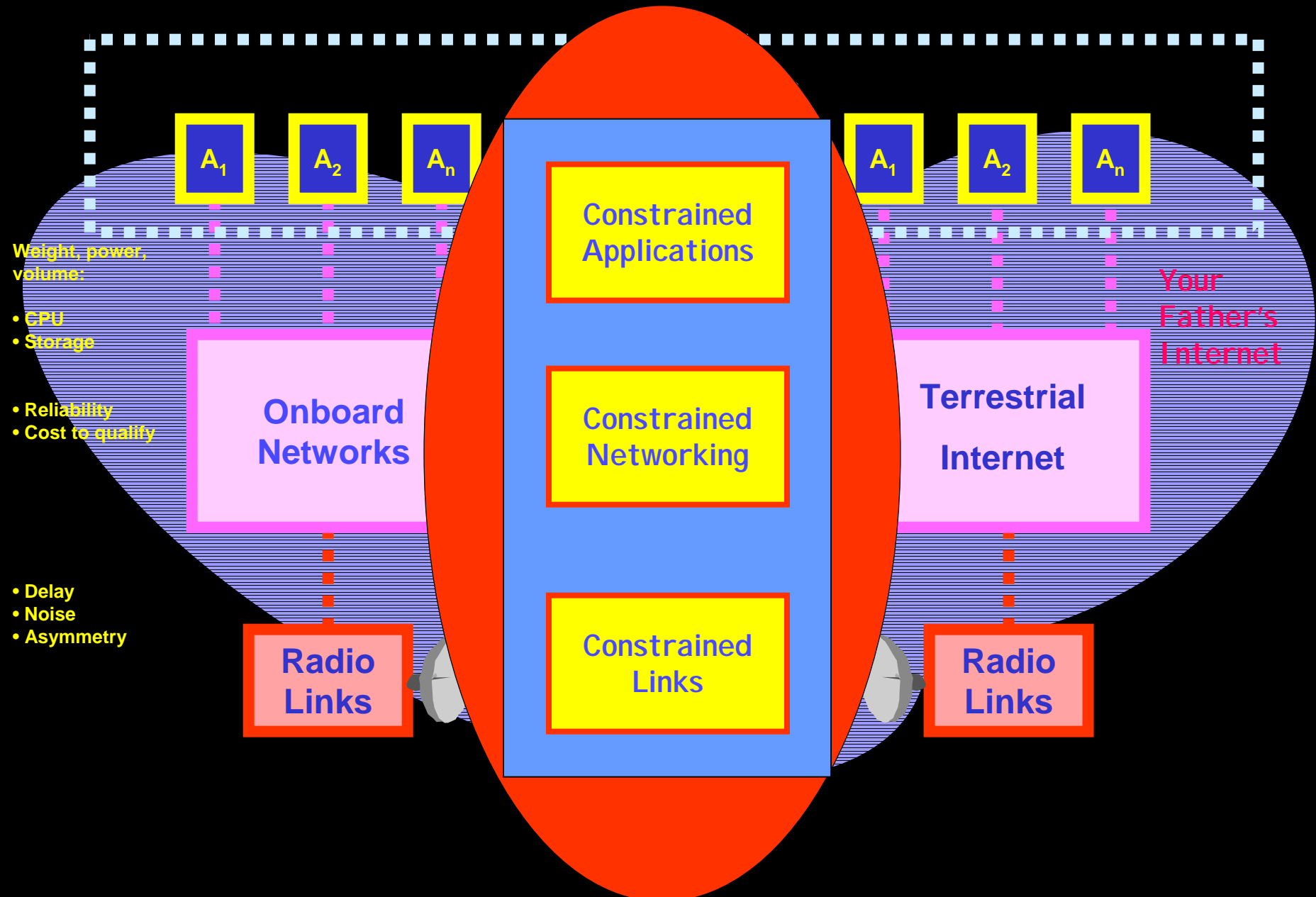
29 Oct 69	2100	LOADED	OP. PROGRAM	CSK
		FOR	ESA BARBER	
		BBV		
	22:30	Talked to SRS		CSK
		Host to Host		
		Left up program		CSK
		running after sending		
		a host dead message		
		to imp.		



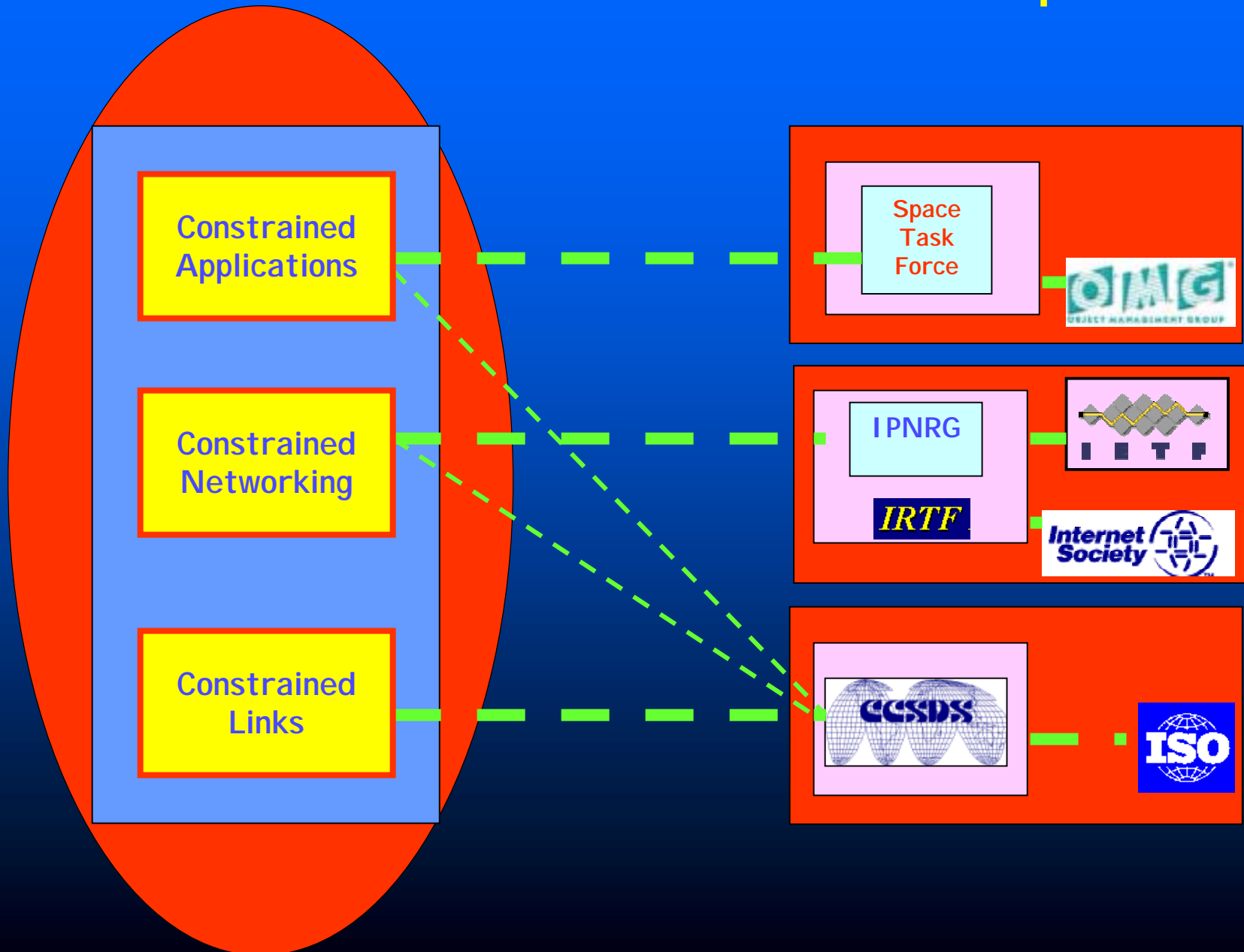
Evolution of the terrestrial Internet



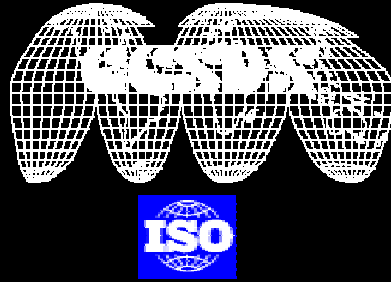
Model of Space/Ground Communications



Current Standardization Options



Consultative Committee for Space Data Systems



Member Agencies

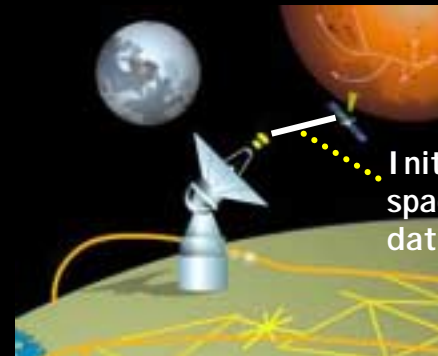
Agenzia Spaziale Italiana (ASI)/Italy.
British National Space Centre (BNSC)/United Kingdom.
Canadian Space Agency (CSA)/Canada.
Central Research Institute of Machine Building
(TsNIIMash)/Russian Federation.
Centre National d'Etudes Spatiales (CNES)/France.
Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V. (DLR)/Germany.
European Space Agency (ESA)/Europe.
Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
National Aeronautics and Space Administration (NASA HQ)/USA.
National Space Development Agency of Japan (NASDA)/Japan.

The Consultative Committee for Space Data Systems (CCSDS) is an international voluntary consensus organization of space agencies and industrial associates interested in mutually developing standard data handling techniques to support space research, including space science and applications

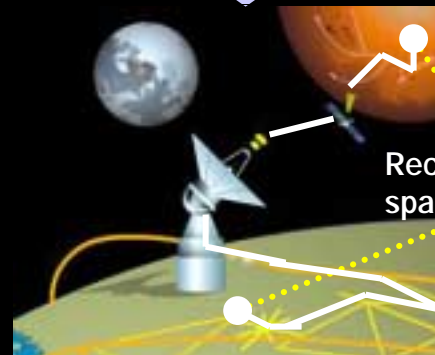
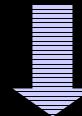
Observer Agencies

Australian Space Office (ASO)/Australia.
Austrian Space Agency (ASA)/Austria.
Belgian Science Policy Office (SPO)/Belgium.
Centro Tecnico Aeroespacial (CTA)/Brazil.
Chinese Academy of Space Technology (CAST)/China.
Communications Research Laboratory (CRL)/Japan.
Danish Space Research Institute (DSRI)/Denmark.
European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
European Telecommunications Satellite Organization (EUTELSAT)/Europe.
Hellenic National Space Committee (HNSC)/Greece.
Indian Space Research Organization (ISRO)/India.
Industry Canada/Communications Research Centre (CRC)/Canada.
Institute of Space and Astronautical Science (ISAS)/Japan.
Institute of Space Research (IKI)/Russian Federation.
KFKI Research Institute for Particle & Nuclear Physics (KFKI)/Hungary.
MIKOMTEK: CSIR (CSIR)/Republic of South Africa.
Ministry of Communications (MOC)/Israel.
National Oceanic & Atmospheric Administration (NOAA)/USA.
National Space Program Office (NSPO)/Taiwan.
Swedish Space Corporation (SSC)/Sweden.
United States Geological Survey (USGS)/USA.

<http://www.ccsds.org> *



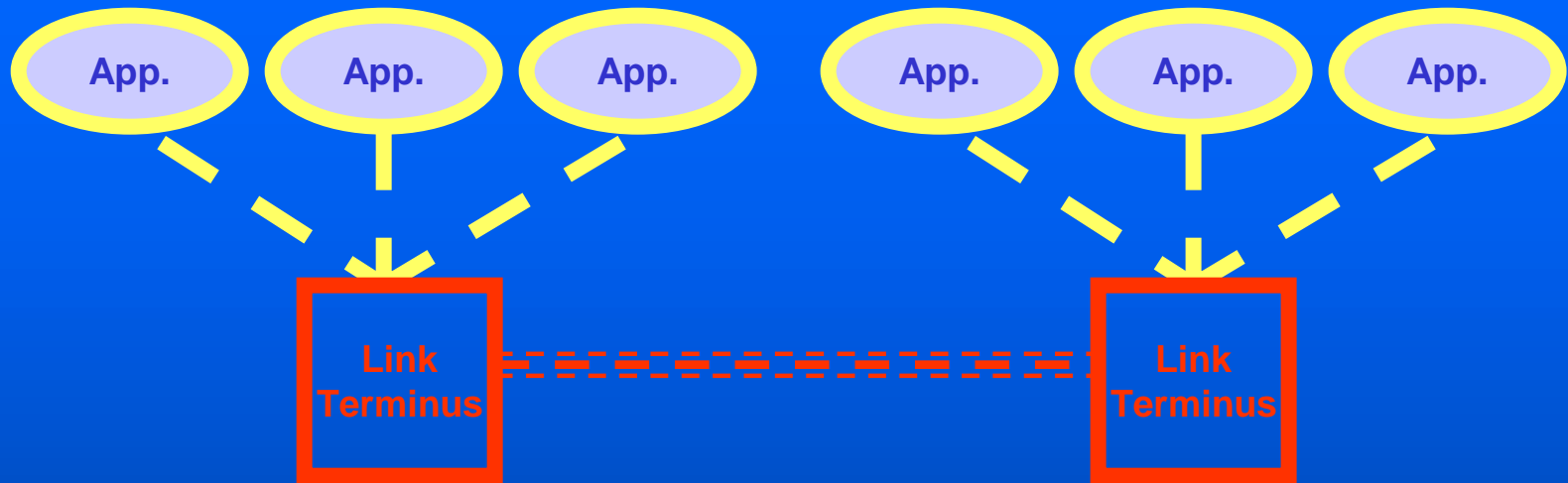
Initial focus:
space/ground
data link protocols



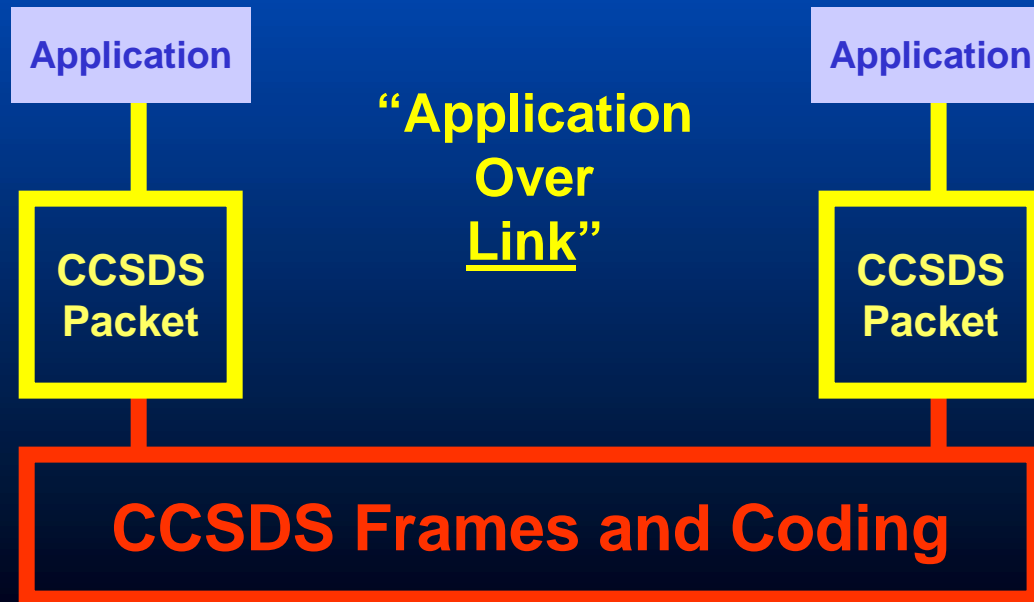
Recent focus:
space networking

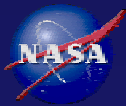


<http://www.scps.org> *

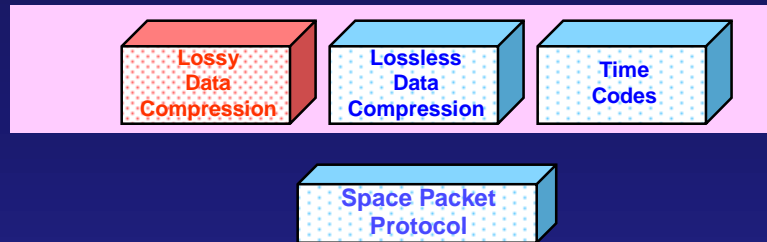


CCSDS Classic

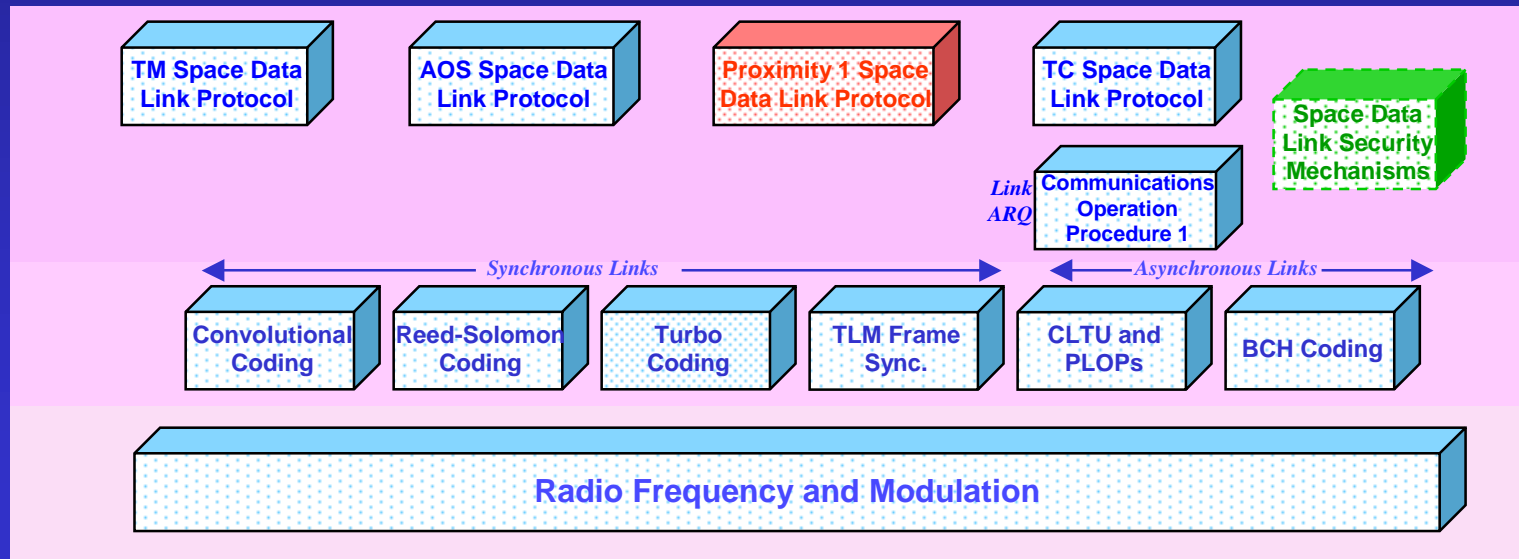




Basic CCSDS Space/Ground Communications Protocol Stack



Application



Link

Physical



CCSDS Recommendation



Draft CCSDS Recommendation



CCSDS Report

CCSDS: The Fleet

Space Domain

Spacecraft Platforms
On-Board Systems
Space Qualified ASICs

CCSDS
Consultative Committee for Space Data Systems

~200 missions, and counting

Ground Domain

Commercial Ground Networks

Command & Telemetry Data Processing

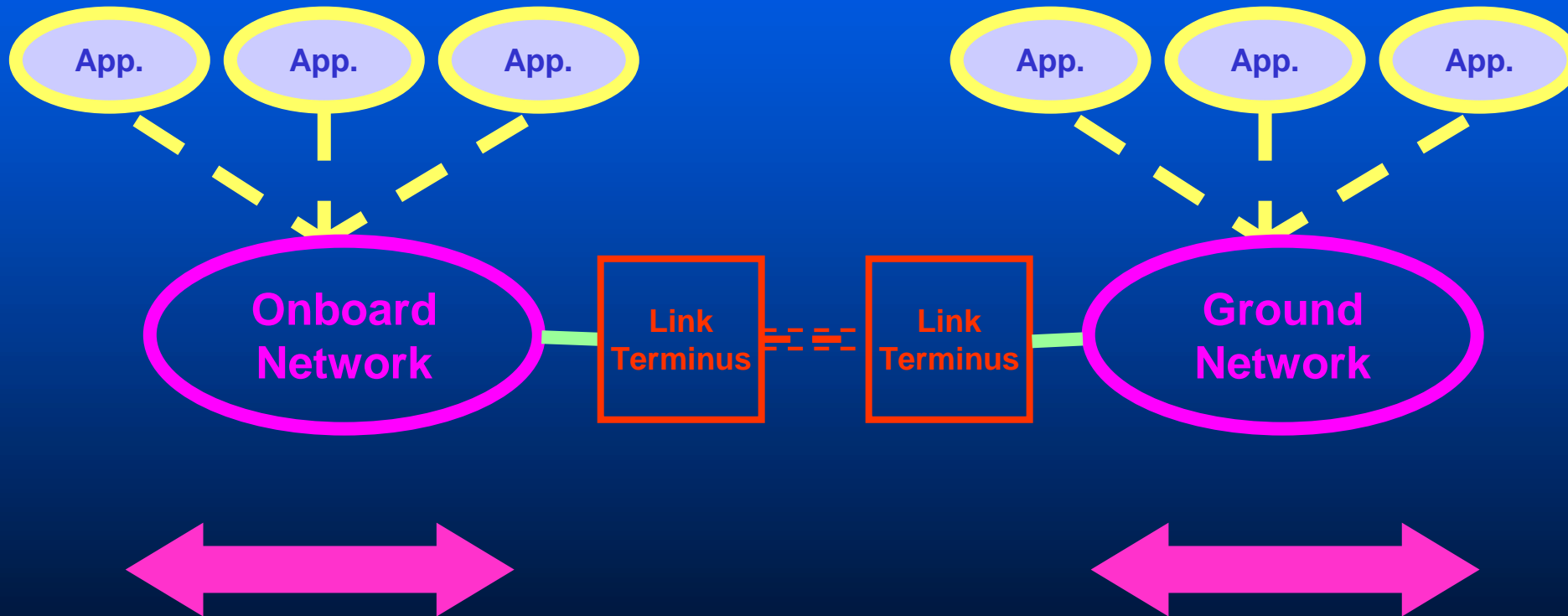
Space Link Extension Forward and Return Services



Emerging
CCSDS

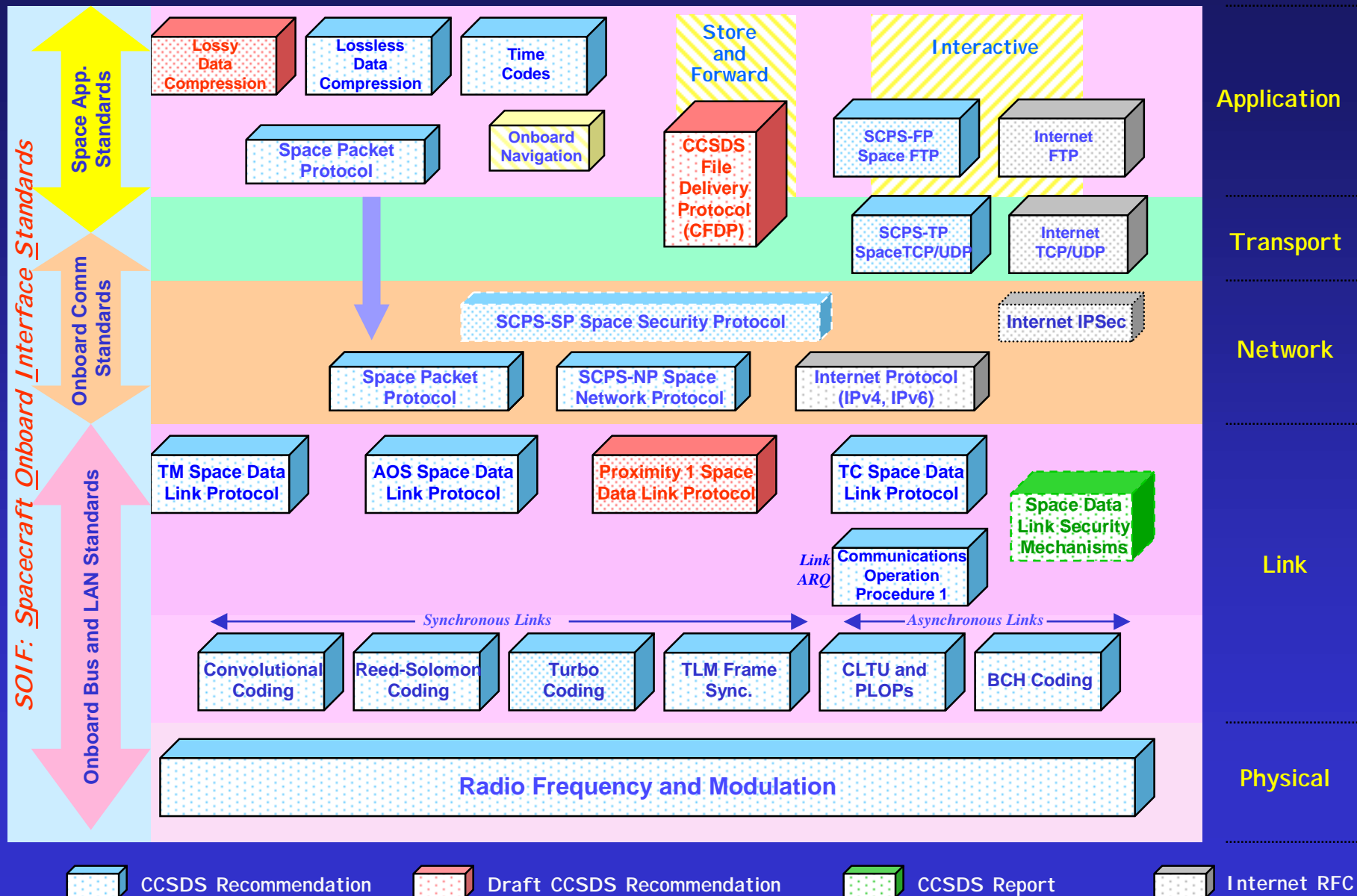


“Application
Over
Network”





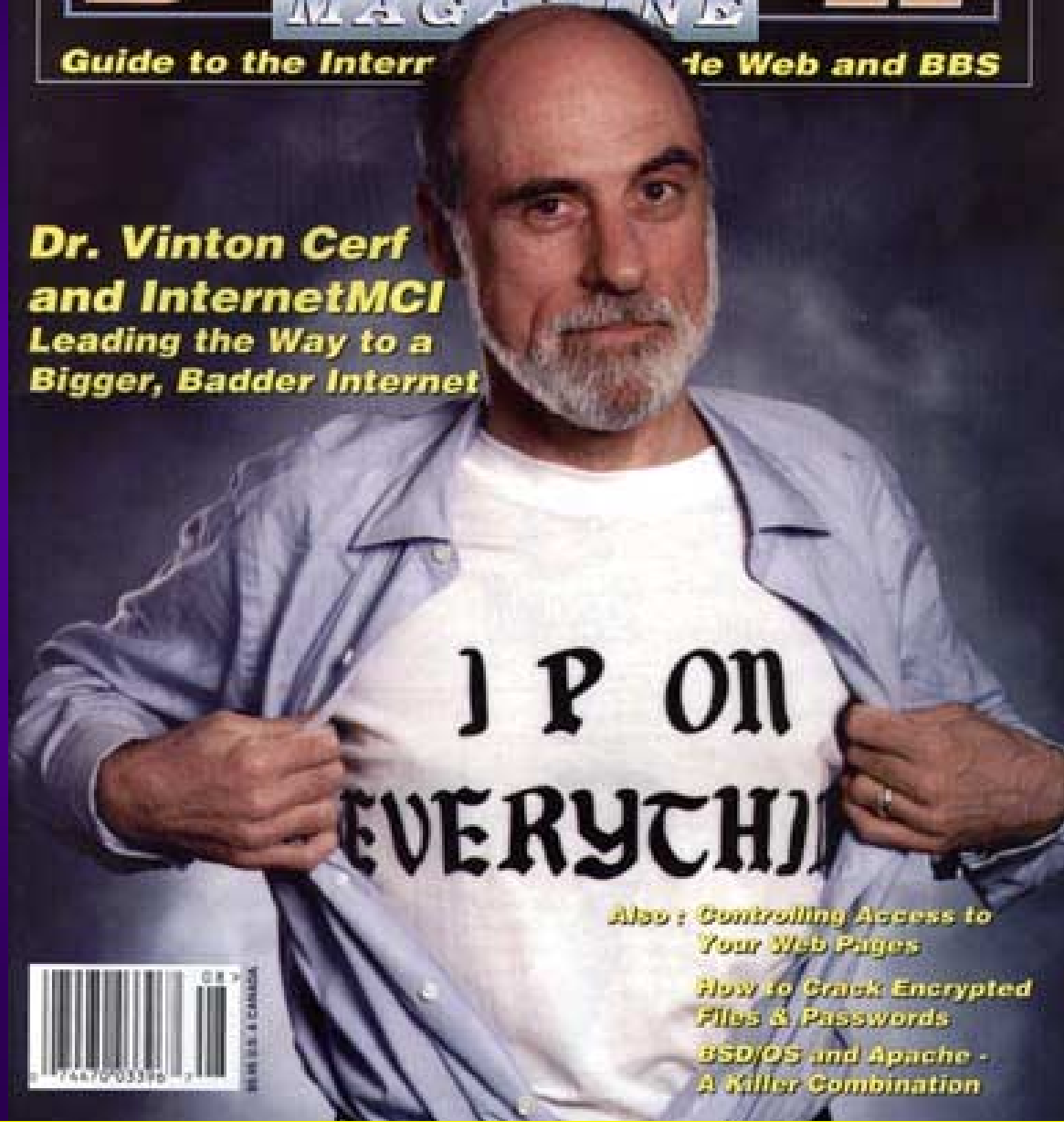
Networked CCSDS Space/Ground Communications Protocol Stack



BOARDWATCH MAGAZINE

Guide to the Internet, the Web and BBS

**Dr. Vinton Cerf
and InternetMCI**
Leading the Way to a
Bigger, Badder Internet



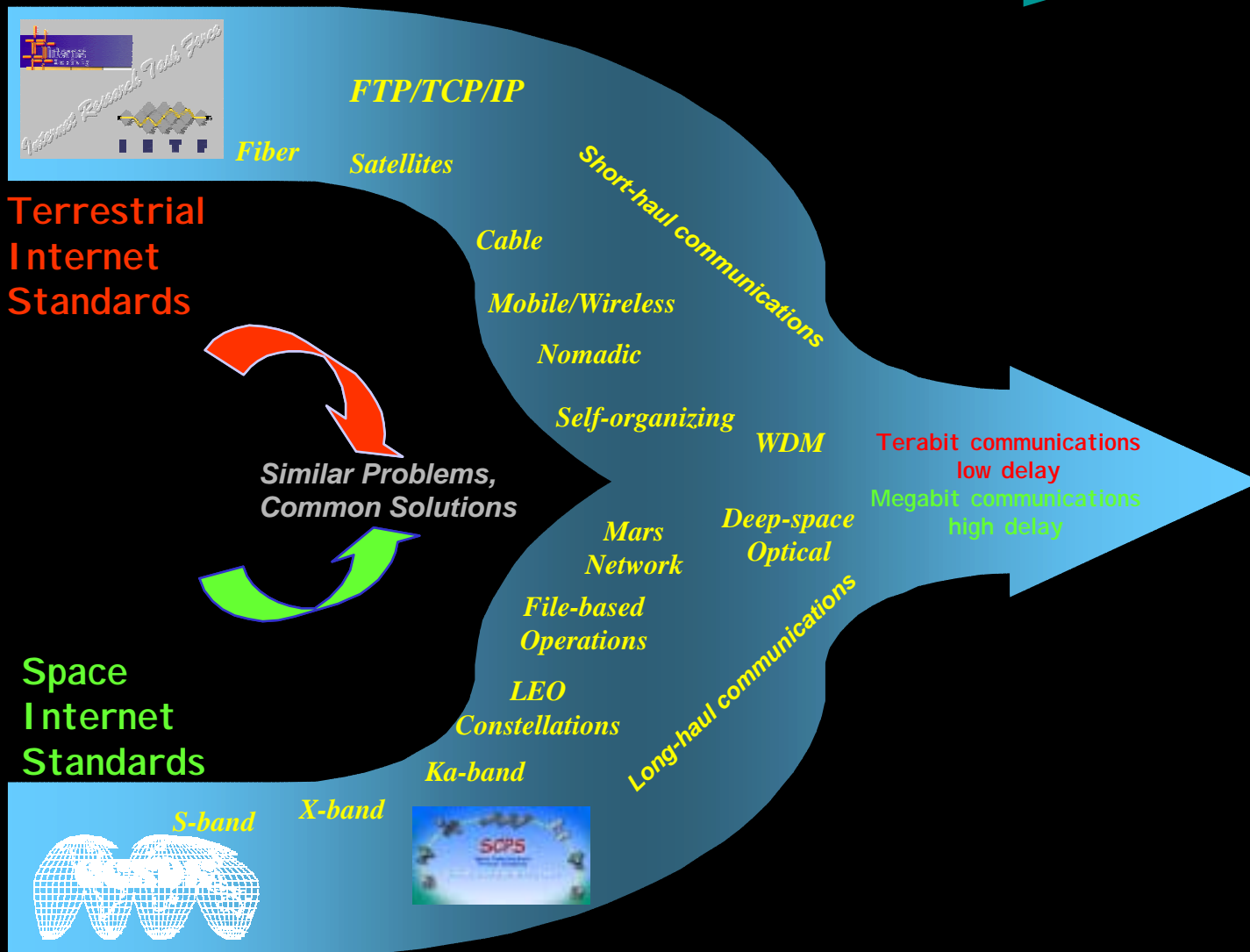
**Also: Controlling Access to
Your Web Pages**

**How to Crack Encrypted
Files & Passwords**

**BSD/OS and Apache -
A Killer Combination**



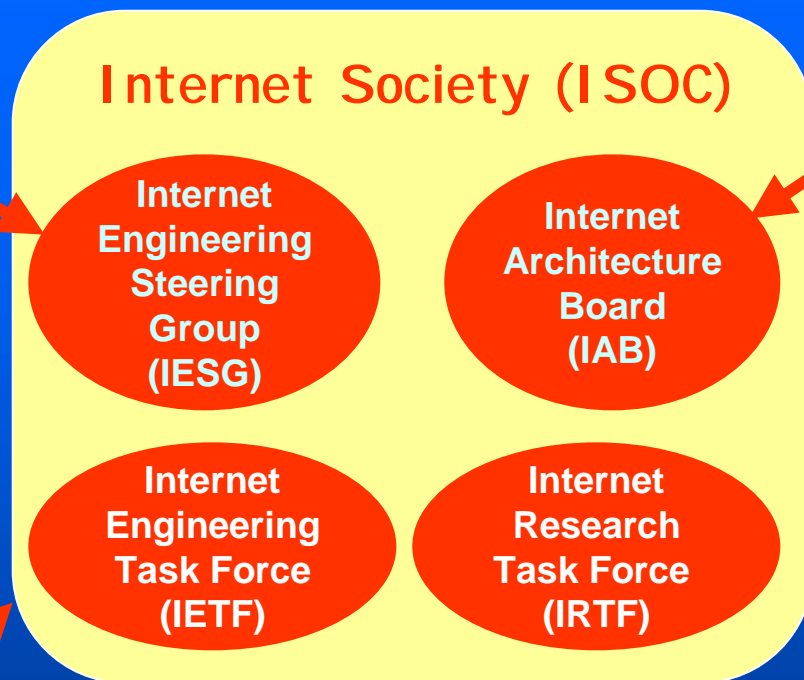
Opportunity for leverage



InterPlaNetary Internet Architecture

The IESG is responsible for technical management of IETF activities and the Internet standards process. The IESG is directly responsible for the actions associated with entry into and movement along the Internet "standards track," including final approval of specifications as Internet Standards.

The IETF is a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet. It is open to any interested individual.



Internet Society (ISOC)

Internet Engineering Steering Group (IESG)

Internet Architecture Board (IAB)

Internet Engineering Task Force (IETF)

Internet Research Task Force (IRTF)

Internet Corporation for Assigned Names and Numbers (ICANN)

ICANN is the non-profit corporation that was formed to assume responsibility for the IP address space allocation, protocol parameter assignment, domain name system management, and root server system management functions

IAB responsibilities include:

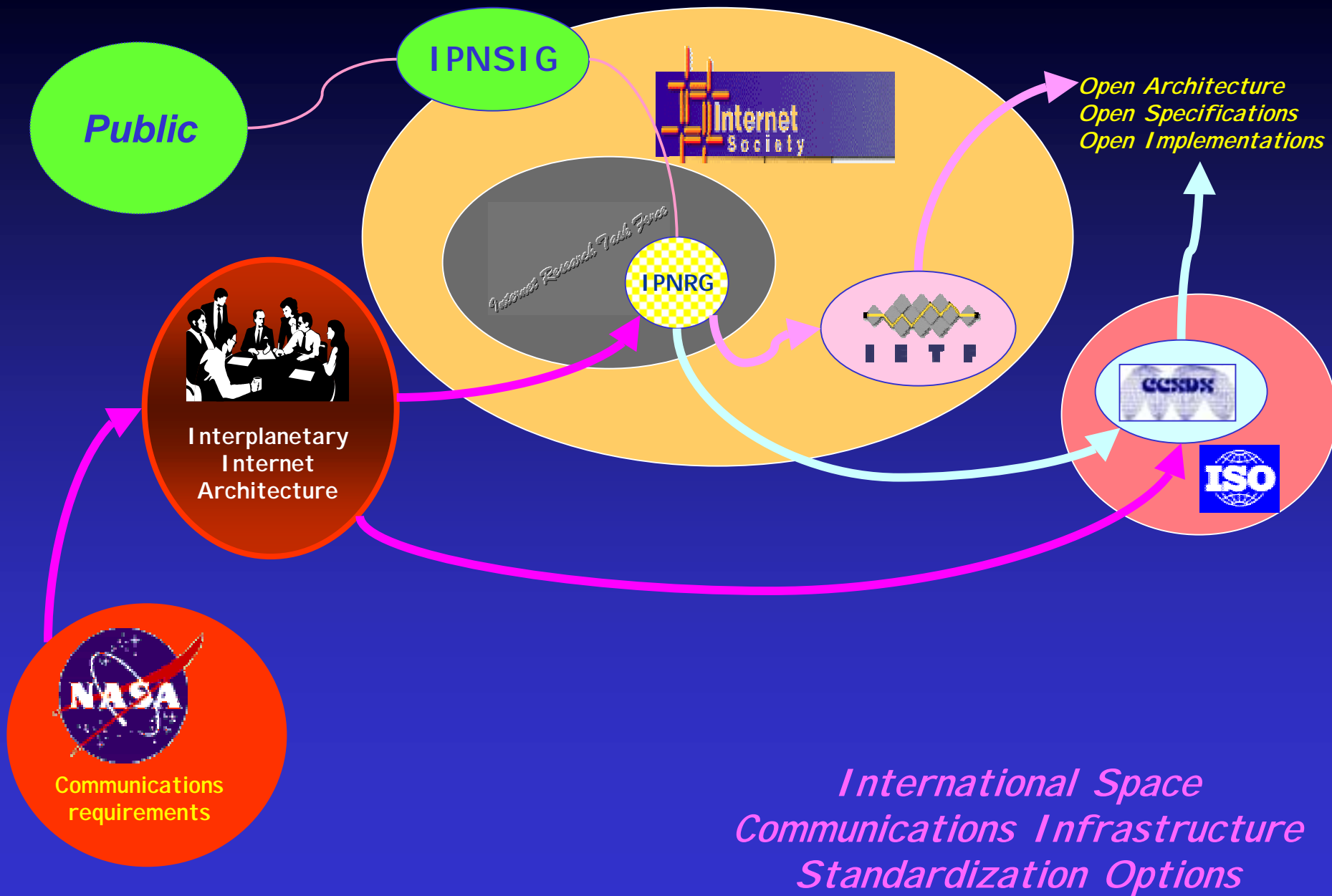
1. IESG Selection,
2. Oversight of the architecture for the protocols and procedures used by the Internet.
3. Oversight of the process used to create Internet Standards.
4. Editorial management and publication of the Request for Comments (RFC) document series
5. External Liaison with other organizations concerned with standards and other issues relevant to the world-wide Internet.
6. Technical, architectural, procedural, and (where appropriate) policy advice to the Internet Society

IRTF Research Groups work on topics related to Internet protocols, applications, architecture and technology. Participation is by individual contributors, rather than by representatives of organizations. The Internet Research Steering Group (IRSG) may from time to time hold topical workshops focusing on research areas of importance to the evolution of the Internet.

Internet Research Task Force (IRTF)



Co-chairs:
Eric Travis
Robert Rumeau



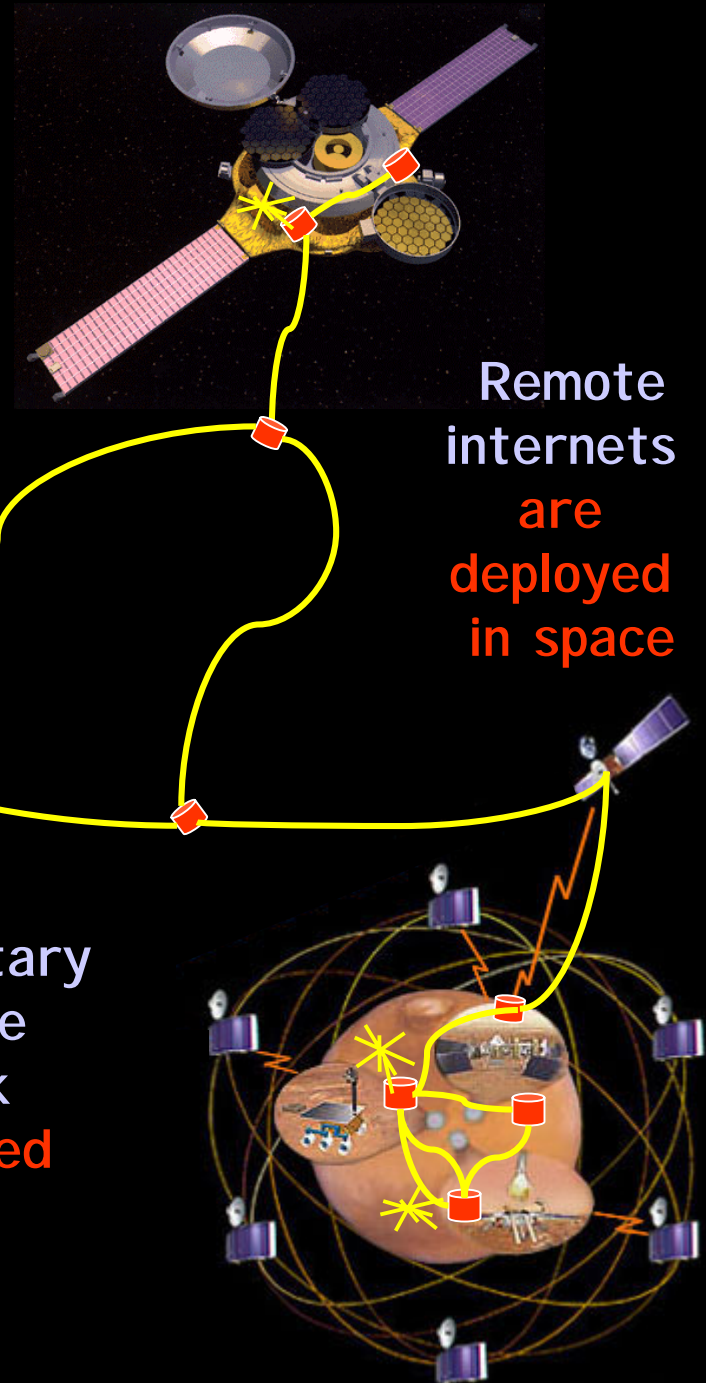
Basics of the IPN Architecture

Space exploration
becomes fully
Internet-based

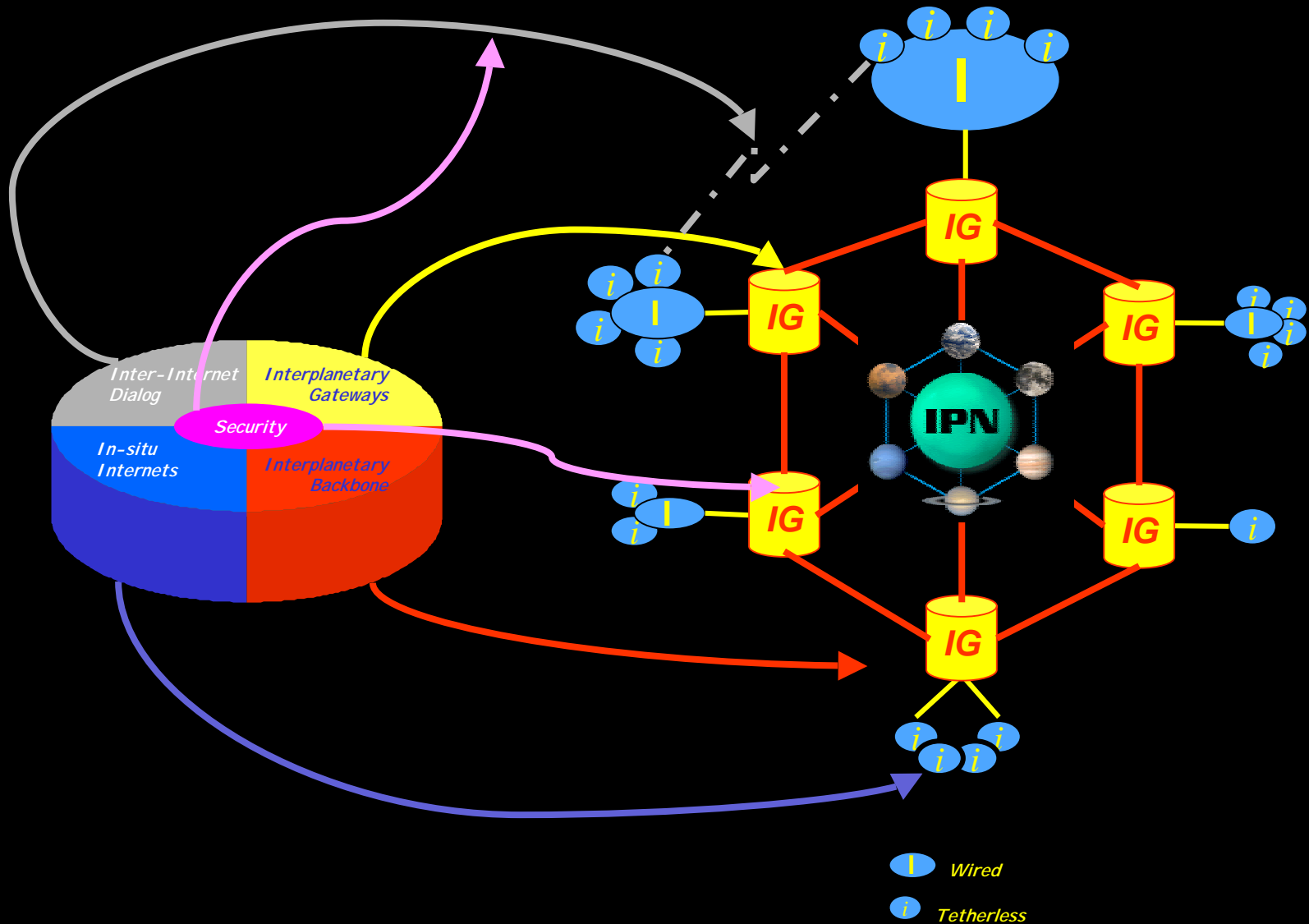
Missions log-on
to the
"Interplanetary
Internet Service
Provider" to
communicate

Remote
internets
are
deployed
in space

An
interplanetary
backbone
network
is deployed

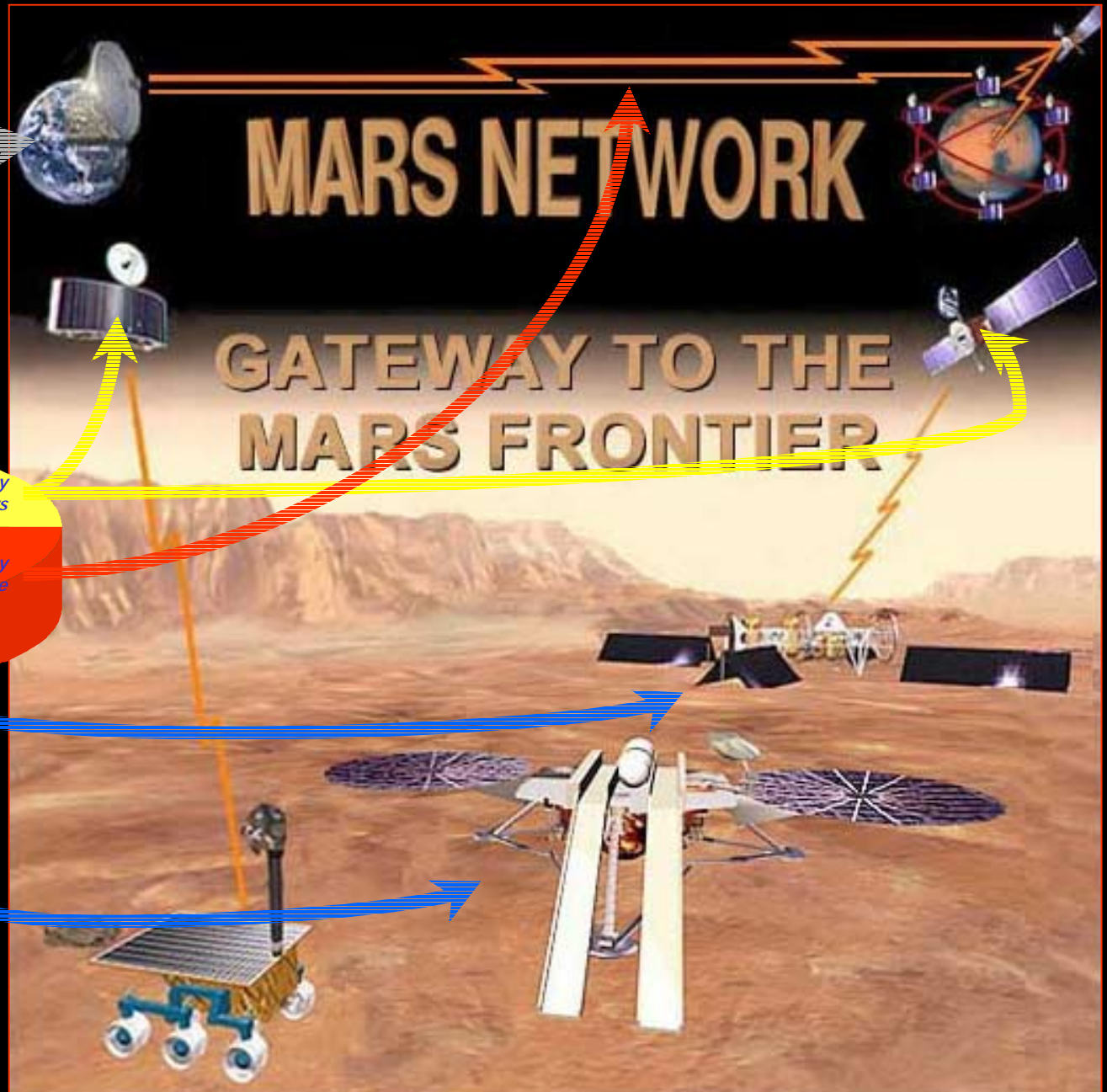
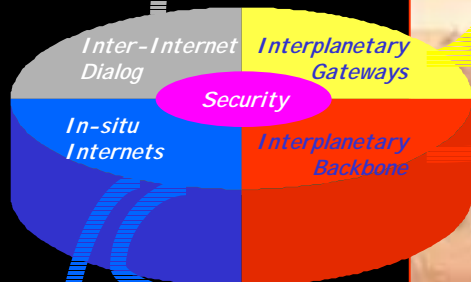


IPN Technology Thrust Areas



MARS NETWORK

GATEWAY TO THE MARS FRONTIER





What is a “deployed internet” in the IPN?

- The IPN architecture differentiates between the “long-haul” backbone with round-trip times measured in minutes and deployed networks that have round-trip time characteristics closer to those for which the Internet was designed
- Any deployed network that has the following attributes is considered a deployed internet:
 - Has an environment that does not inherently preclude the use of (possibly enhanced) Internet protocols
 - It is *possible* to route to all nodes in the network without resorting to use of long-haul infrastructure (or protocols)

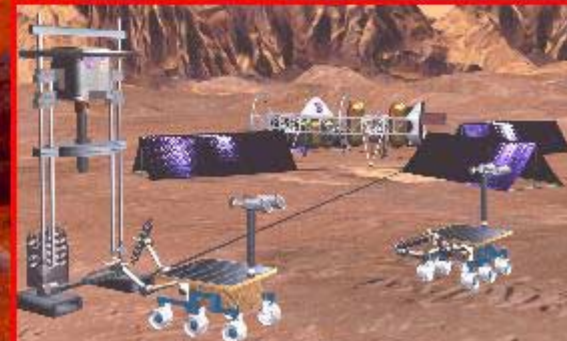
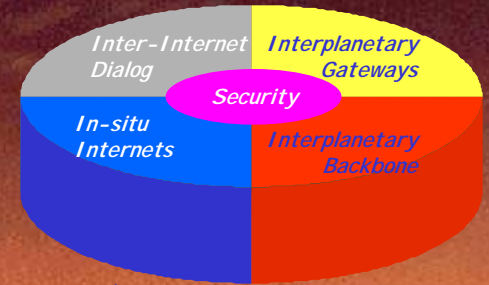
Deployed Internets: A Broad Range of Possible Configurations

- A single lander with an IPN gateway to a (real or virtual) internal network
- Small number of cooperating robots on planetary surface (e.g. Single lander, single rover)
- Orbiter-to-surface communication and coordination (e.g. sample return recovery)
- Multiple beyond-line-of-sight missions connected by low-orbit communication satellites
- Planet-stationary satellites for relay and gateway functions
- Spacecraft on-board LANs
- The Earth's Internet

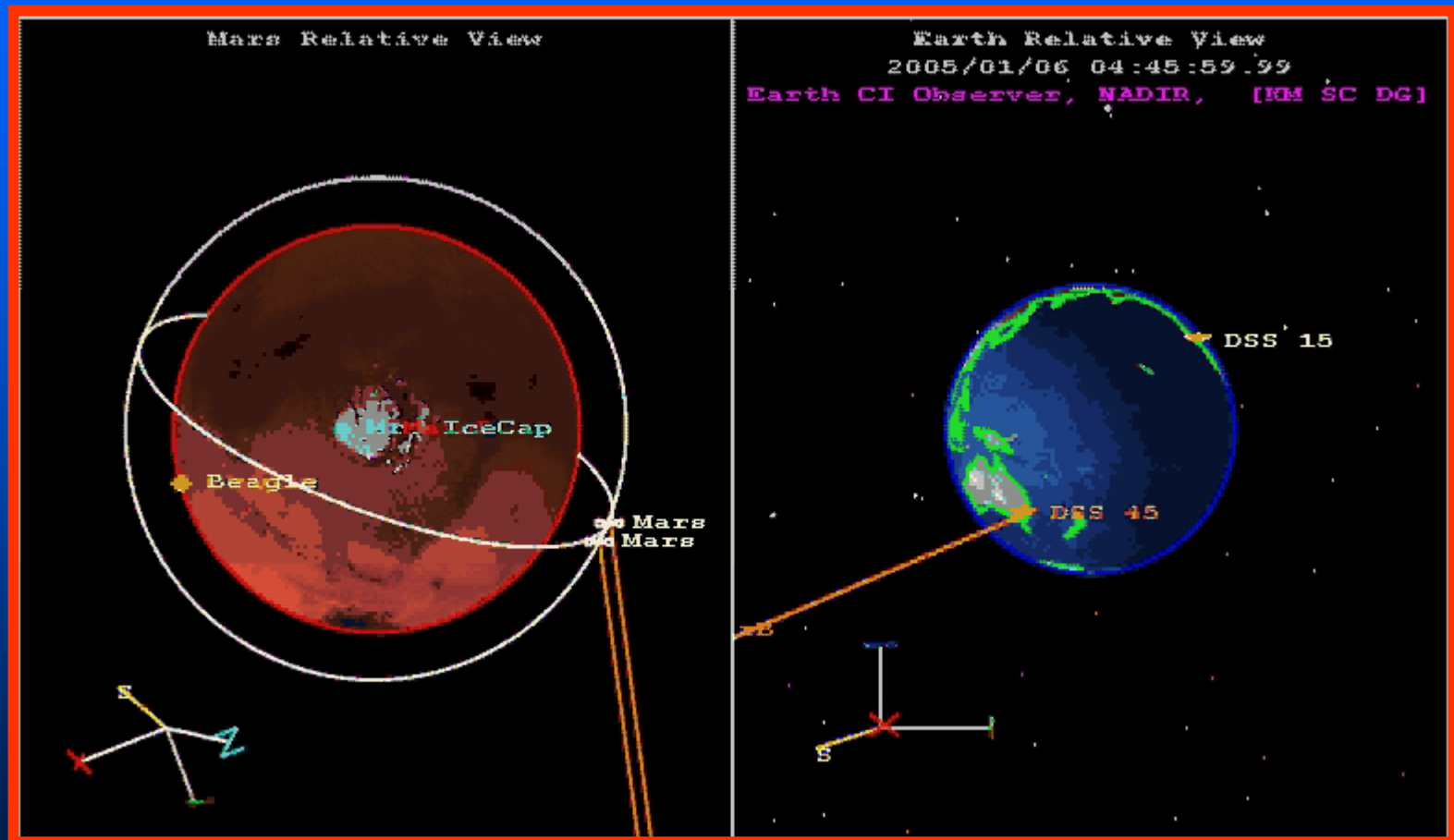


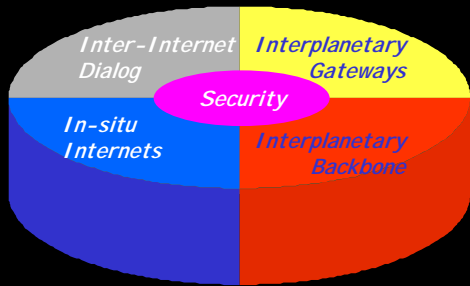
Deployed In-Situ Internets

Untethered
Mobile
Mass constrained
~~Location-Location-Location~~
Power-Power-Power



Even "Simple" Configurations Aren't Simple





What's a Backbone?

- * *A set of high-capacity, high-availability links between network traffic hubs*
 - Terrestrial backbone links are between hubs like Houston and Chicago.
 - Interplanetary backbone links are between hubs like Earth and Mars.

Differences Between Terrestrial and Interplanetary Backbones

	Terrestrial	Interplanetary
<i>Delay (sec)</i>	< .1	10 to 10,000
<i>Connectivity</i>	Wired; structural, continuous	Radiant; operational, intermittent
<i>Medium</i>	Copper, glass	Space; high BER
<i>Deployment \$</i>	“low”	Very high
<i>Operations \$</i>	“low”	High (power is costly)
<i>Repair, upgrade \$</i>	“low”	Very high

What These Differences Imply

- Cost per second of transmission is very high, so...
 - *Don't waste transmission opportunities.*
- Intra-backbone connectivity might never be end-to-end, so...
 - *Don't rely on end-to-end connectivity* for protocol operations. Use store-and-forward techniques.
- End-to-end round trip time may vary from minutes to weeks, so...
 - *Don't rely on negotiation* or other conversational protocol mechanisms; by the time a conversation converges, the reason for it may have passed. Make protocol decisions autonomously, locally.

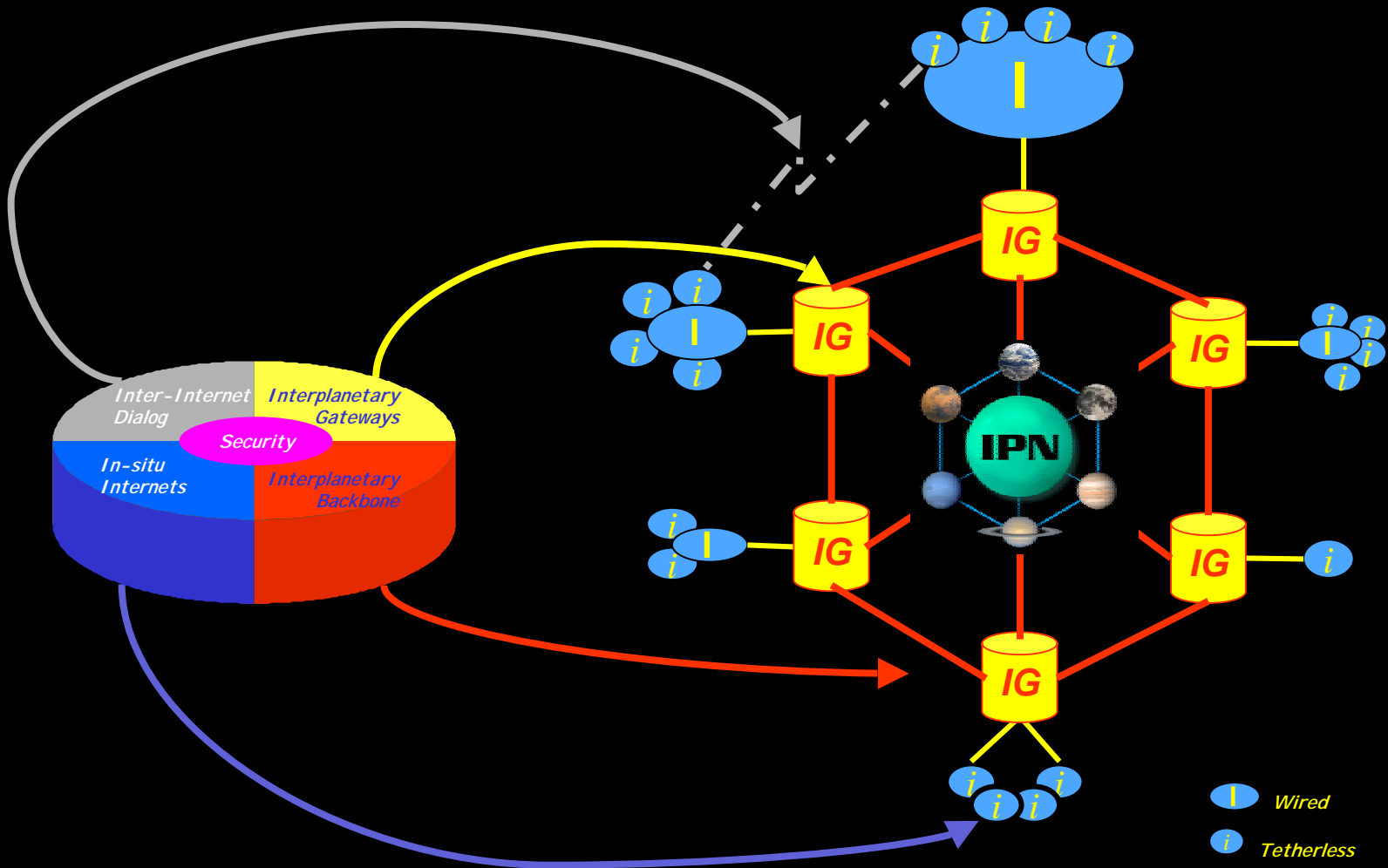
What Won't Work

- Absence of automated protocol (the status quo).
 - It doesn't scale up. Network operations cost would be too high.
- Internet protocols (TCP, UDP, IP) or other protocols designed for terrestrial networks.
 - They rely on conversational protocol mechanisms and/or continuous end-to-end connectivity.

What To Do Instead

- **New application protocols** that don't rely on in-order delivery of byte streams.
- **New bundle-oriented protocols** at the transport and network layers.
 - “Custodial” store-and-forward operation.
 - Concurrent transmission, out-of-order delivery.
- **New reliable link layer protocol.**
 - Point-to-point retransmission over interplanetary distances.
 - Sub-layer of underlying CCSDS protocols for coding and forward error correction, to minimize the need for retransmission.

Interplanetary Dialogs: communicating in a fundamentally disconnected environment



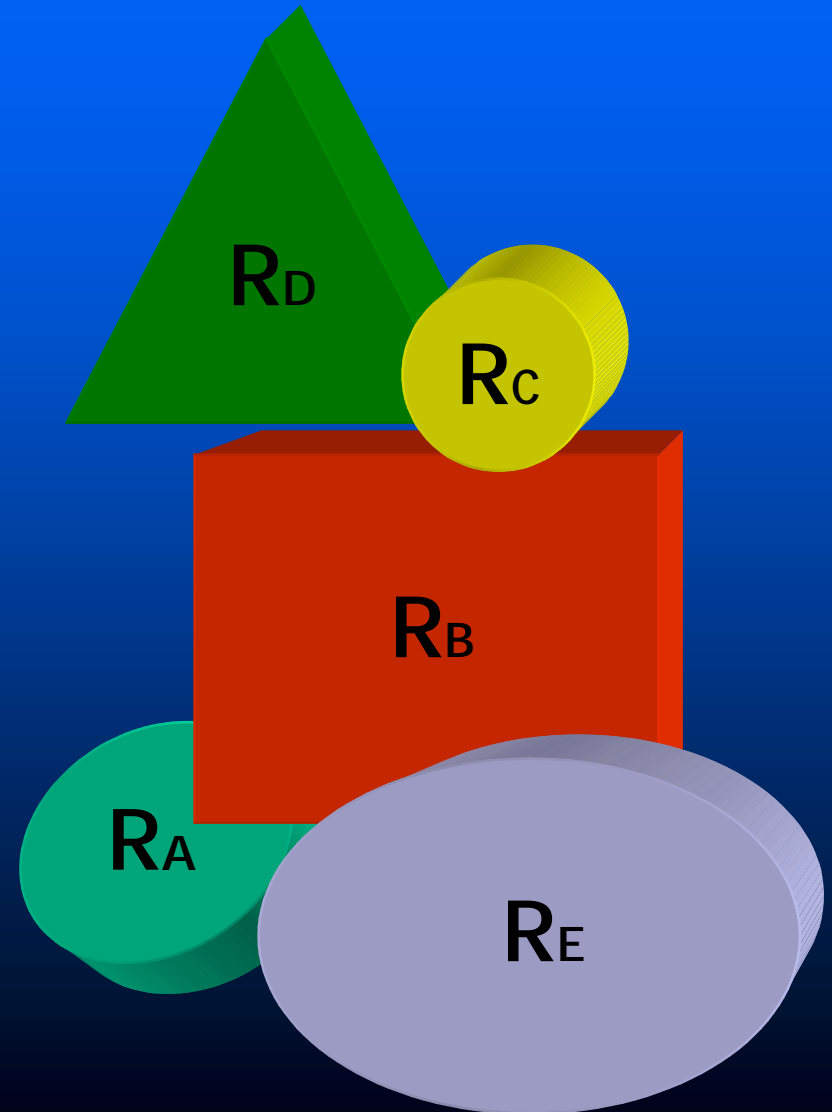
Interplanetary Dialogs: *Design Principles*

- *Intermittent connectivity suggests an Email-like architecture*
 - Common “Handling Instructions” for a data collection
 - Network must accommodate the persistence and transfer of state
- *Late-Binding*
 - We seek functional independence of remote Internets - a single address space across the entire IPN would couple all parts of the system to evolve at the same rate.
 - Therefore: separate addressing domains for each internet. Administrative names converted to local addresses only at the destination IPN region
- *Names (not addresses) are the means of reference*
 - Names have two parts: a routing handle (specifies the IPN region) and an administrative part (specifies the DNS name)
 - Routing between IPN regions based upon routing handle
- *Indirection*
 - Inherent dependence on intermediate relay agents
- *Custodial transfer*
 - Intermediate nodes assume possibly-long-term responsibility for data forwarding
 - “Bundles” as a common end-to-end transfer mechanism

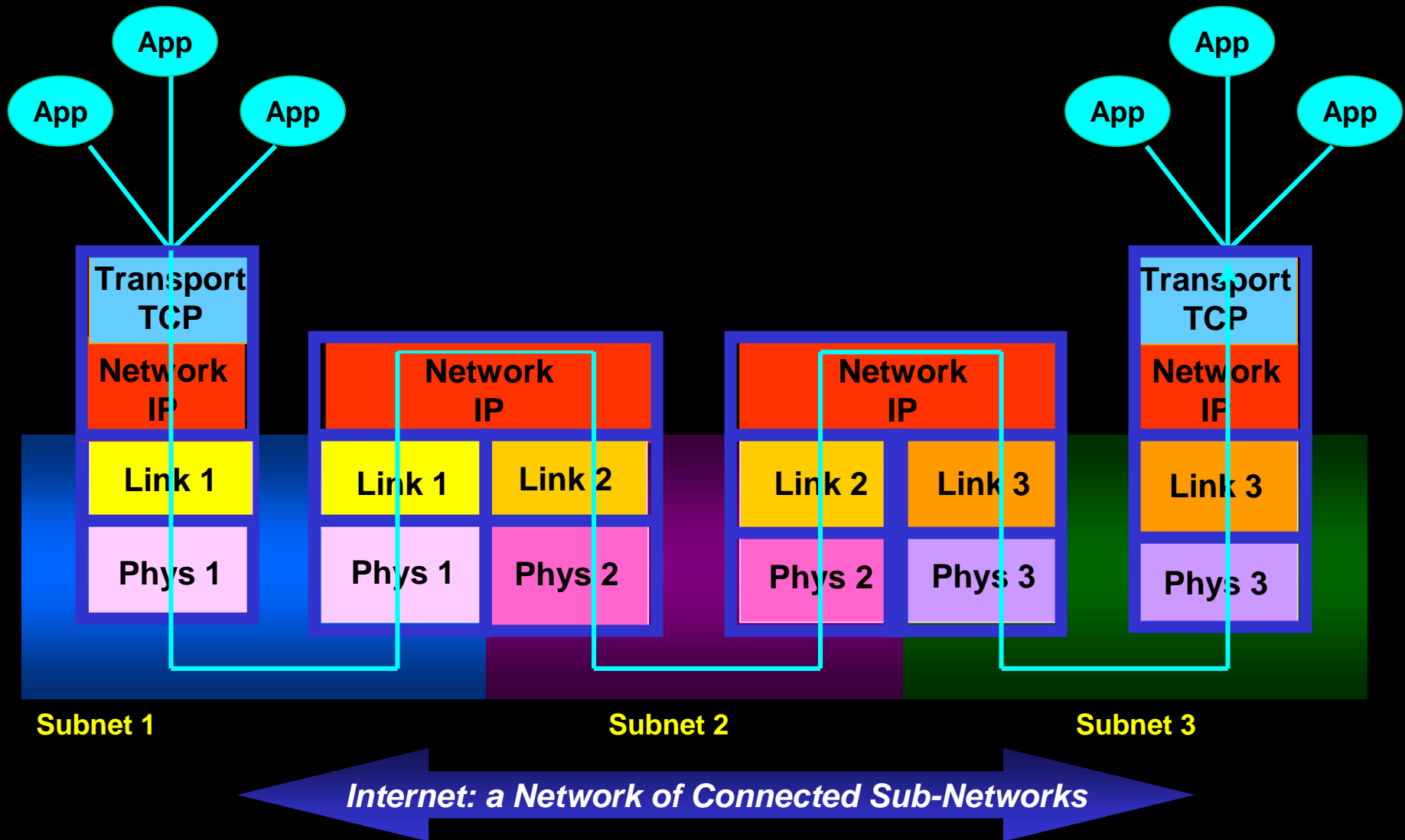
The Interplanetary Internet:

An overlay network for interconnection of regional internets

- A *region* is an area where the relevant characteristics of communication are homogeneous
- One can define regions that are based upon:
 - Communications capability
 - Quality of Service Peerings
 - Security (levels of trust)
 - Degree of resource management
 - Etc.
- Traversal of two or more regions will affect the nature of communications

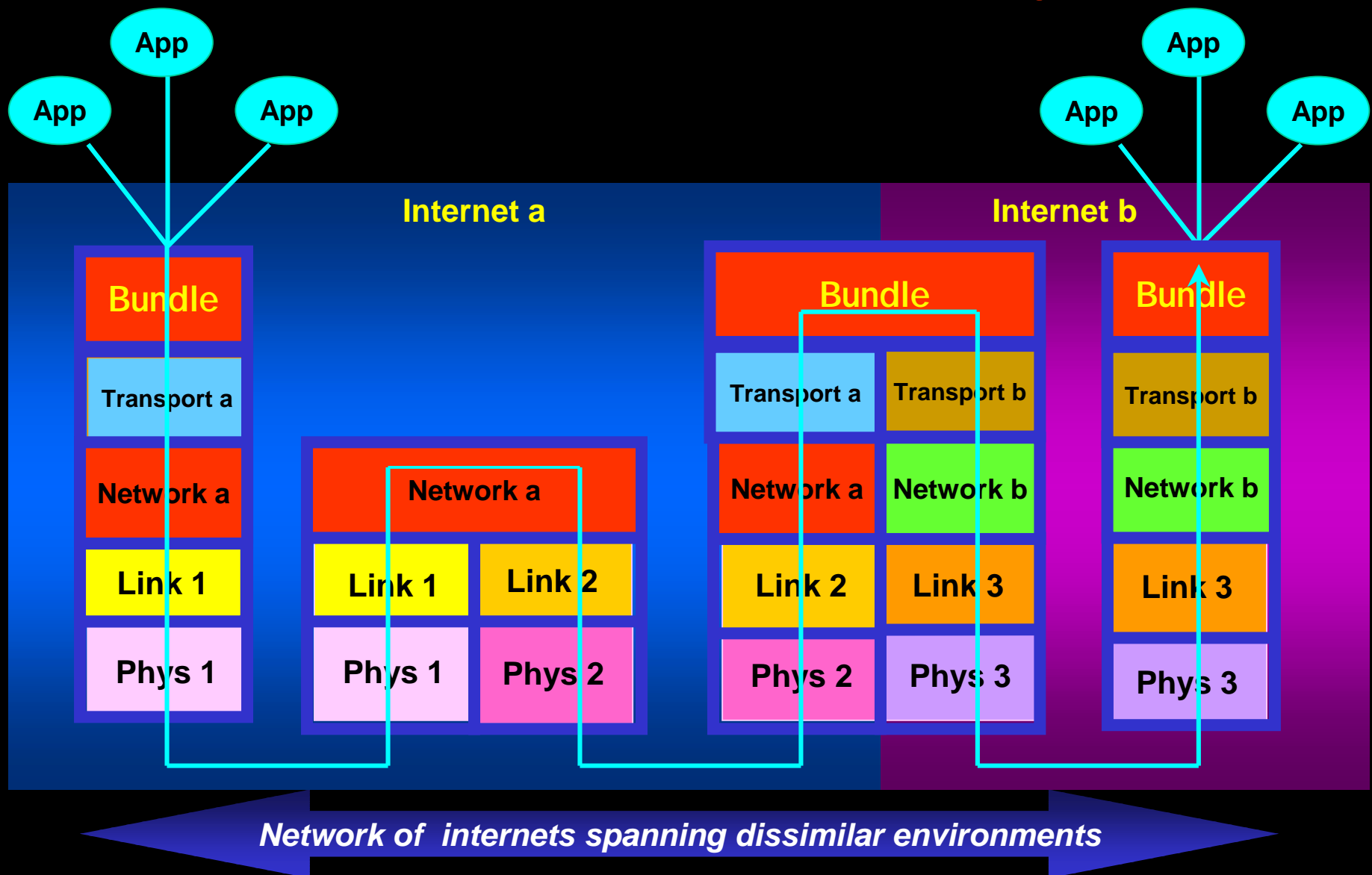


IP: the "Thin Waist" of the Earth's Internet

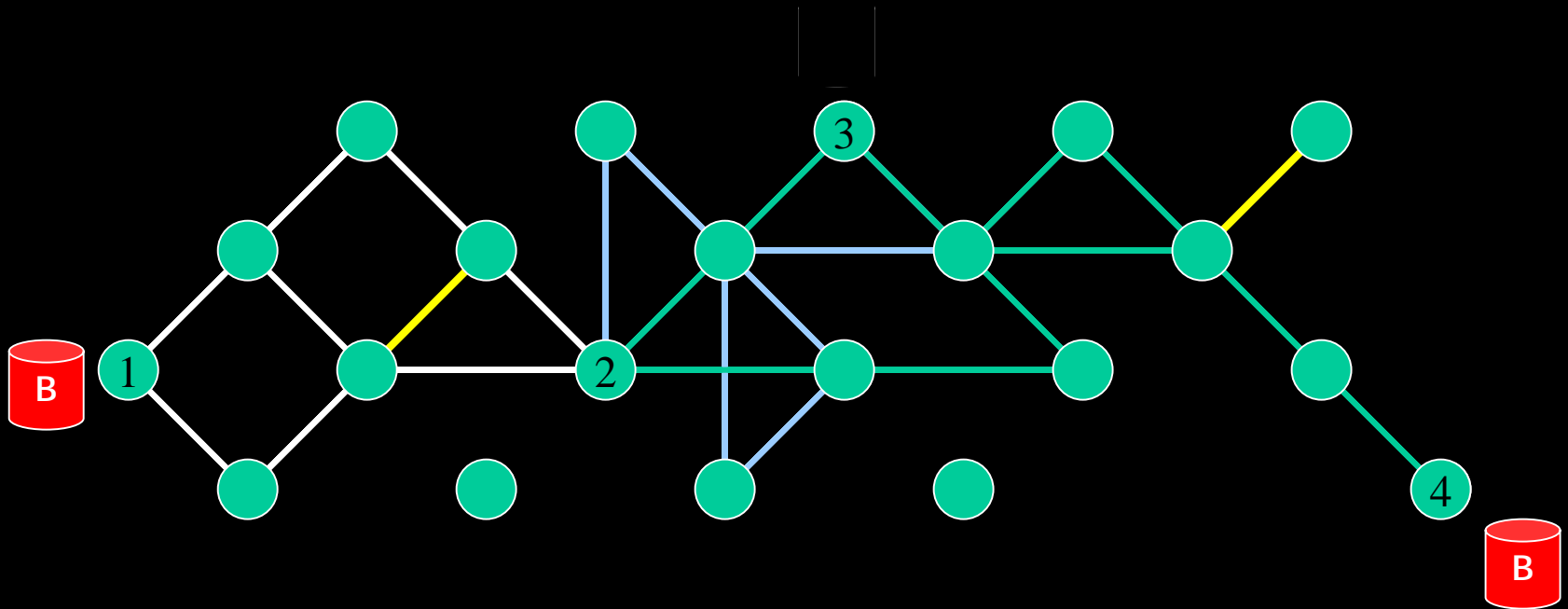


Bundles: A Store and Forward Overlay

The "Thin Waist" of the Interplanetary Internet



Bundling Spans Temporal Discontinuities Between Networks



“Persistence of Vision” provides
the illusion of
end-to-end connectivity

Names: New Requirements

- Names are **tuples**

{ icestation_zebra.hudsonbay.com, europa.jupiter.sol }

Administrative Name

- Opaque outside associated routing domain
- Bound to address only upon entry into its routing domain

Routing Domain

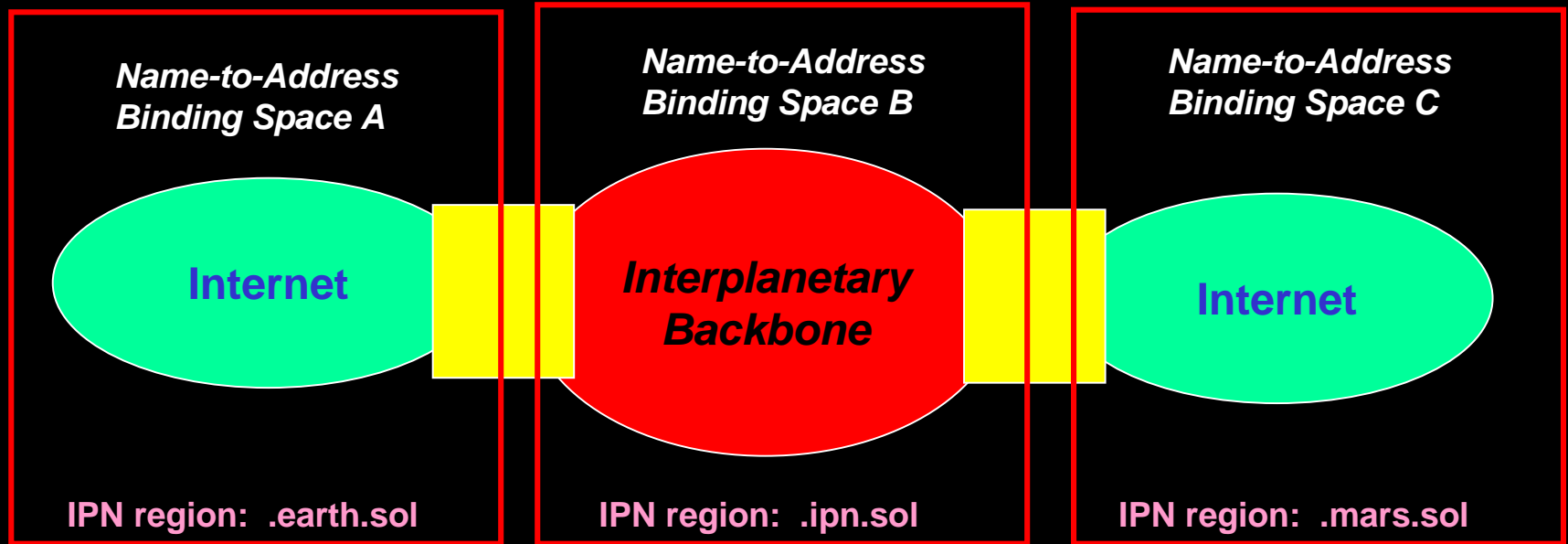
- Specifies an IPN region where the administrative name has significance
- Used as a label for routing through "bundlespace"

 ***Name tuples must be carried end-to-end within each "bundle"***

 ***Names may refer to persistent objects rather than physical entities***

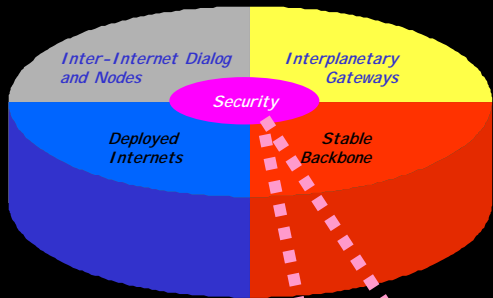
Single Name Space, Late Name-to-Address Binding(s)

Name Space - Common Across All Internets



Name: {admin part: **www.bughunter.org**,
routing part: **earth.sol** }
Local Address: 137.79.10.232

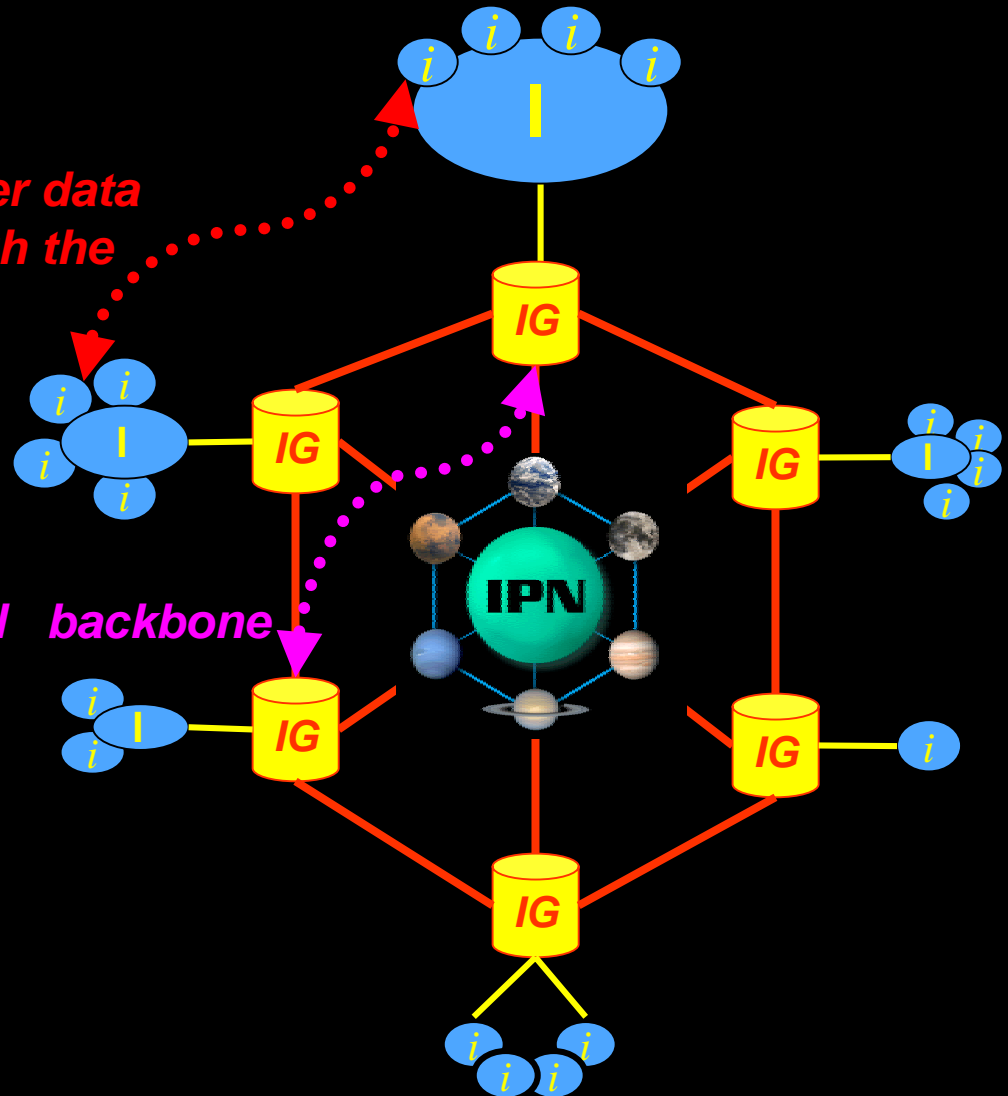
Name: { admin part: **www.rockshop.com**,
routing part: **mars.sol** }
Local Address: 137.79.10.232



IPN Security

*Security of user data
flowing through the
IPN*

Security of the IPN backbone



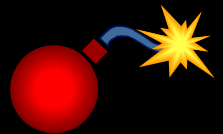
IPN Security Requirements

access control to the IPN will be required because space-based assets will have limited available resources.

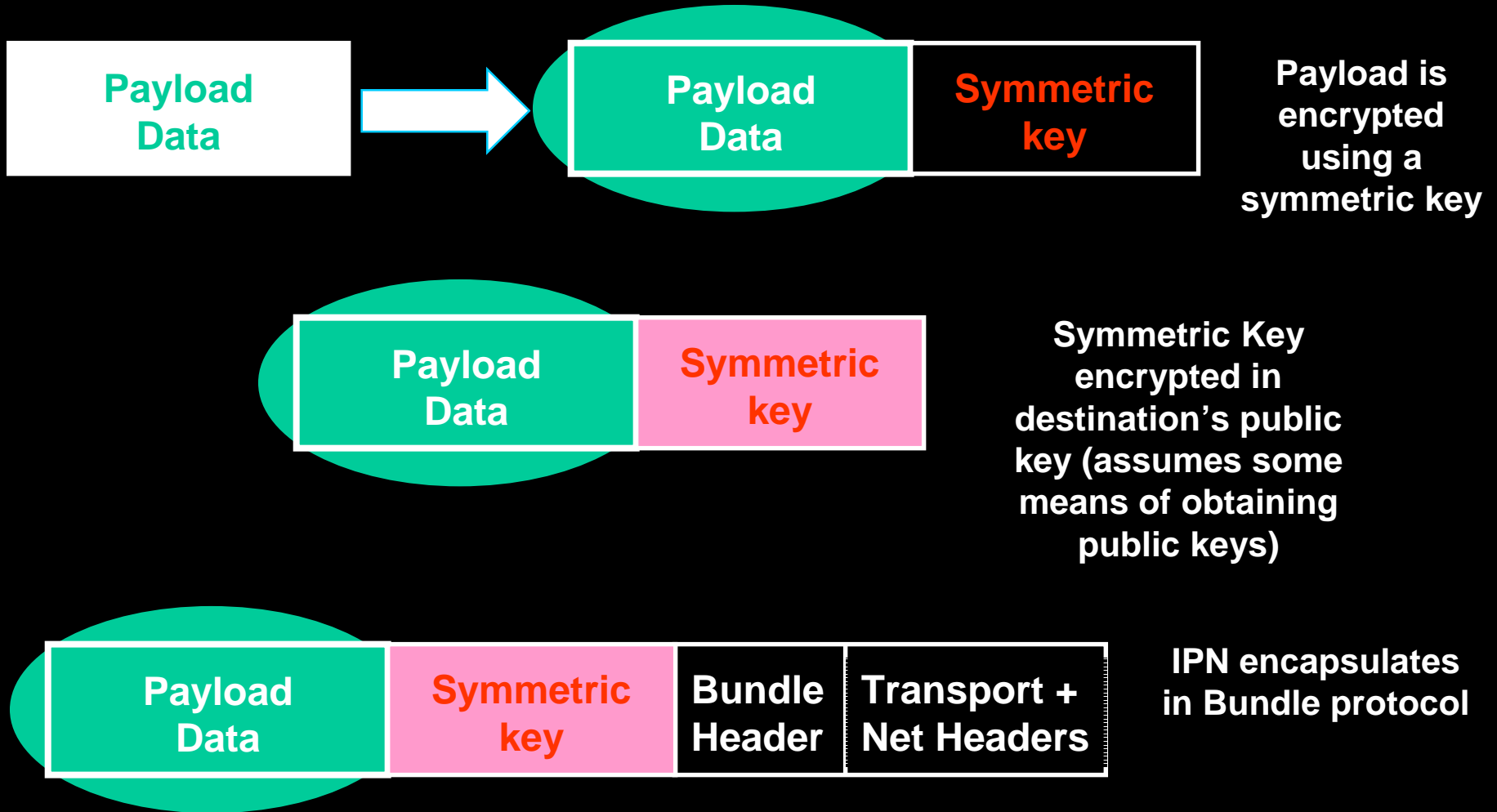
authentication will be required to perform access controls.

data integrity will be required to assure that what was sent *is* received.

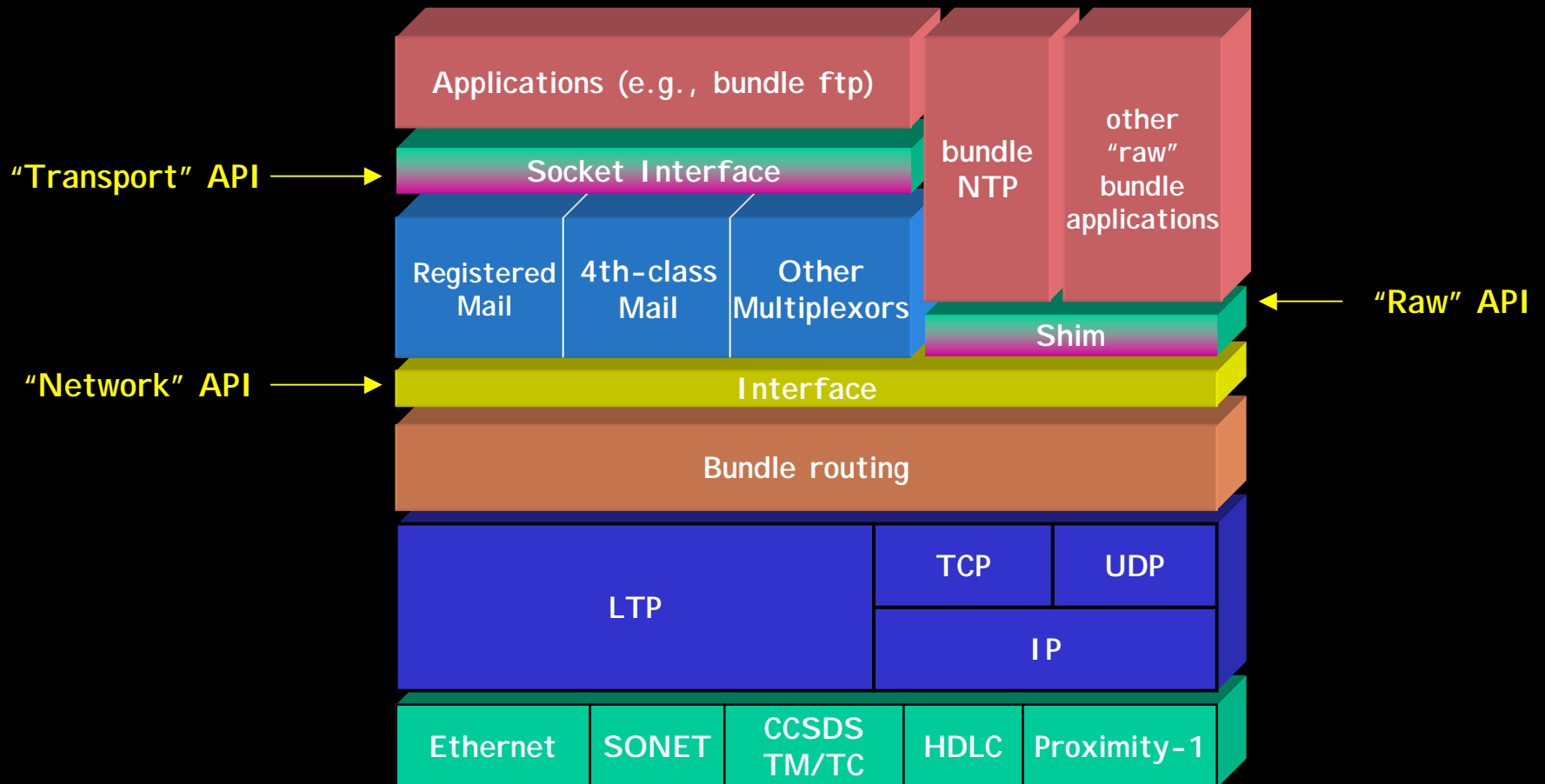
data privacy will be required to assure that unauthorized users cannot obtain information.



Email Key/Encryption Model for IPN



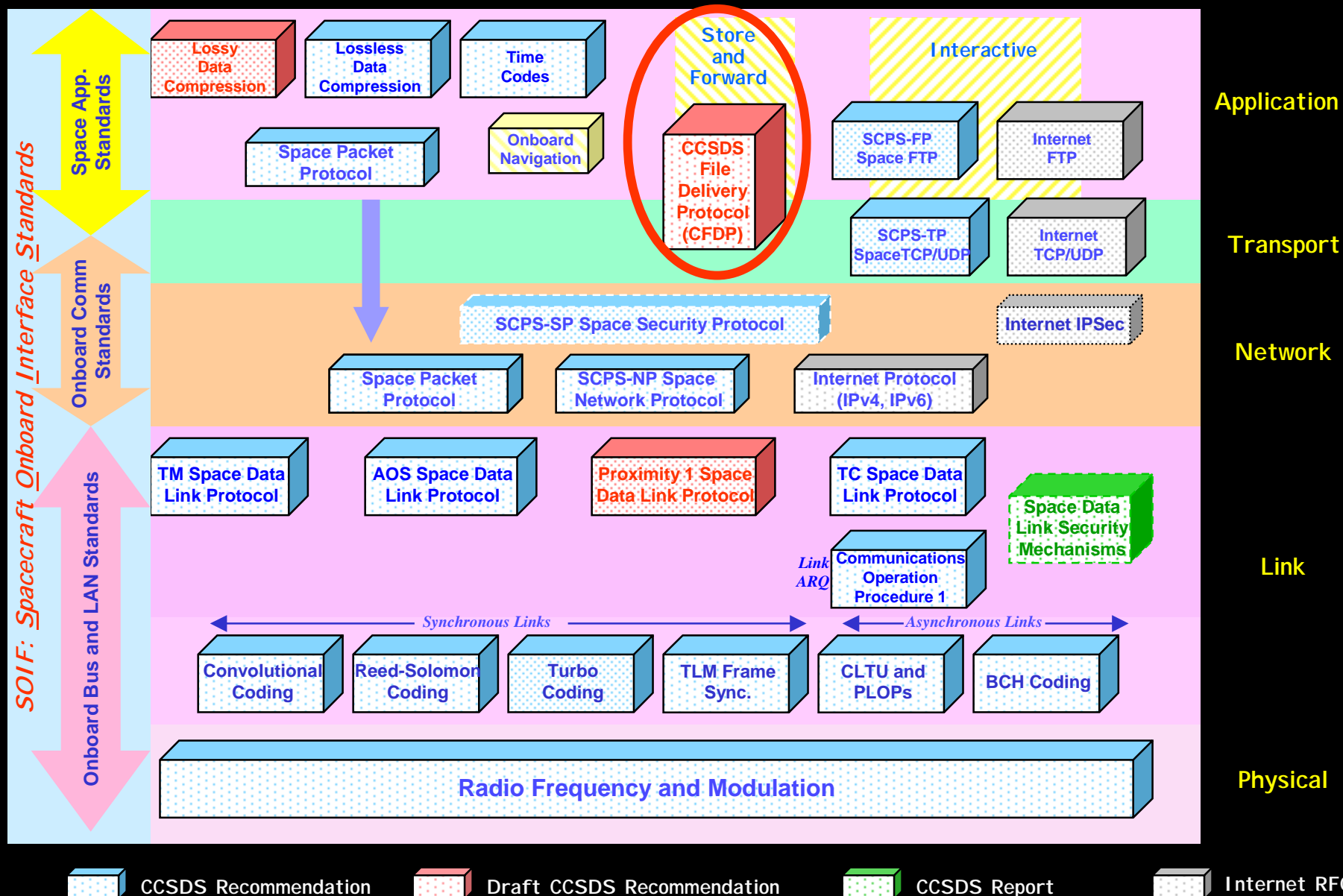
"Bundlespace" Service Layering



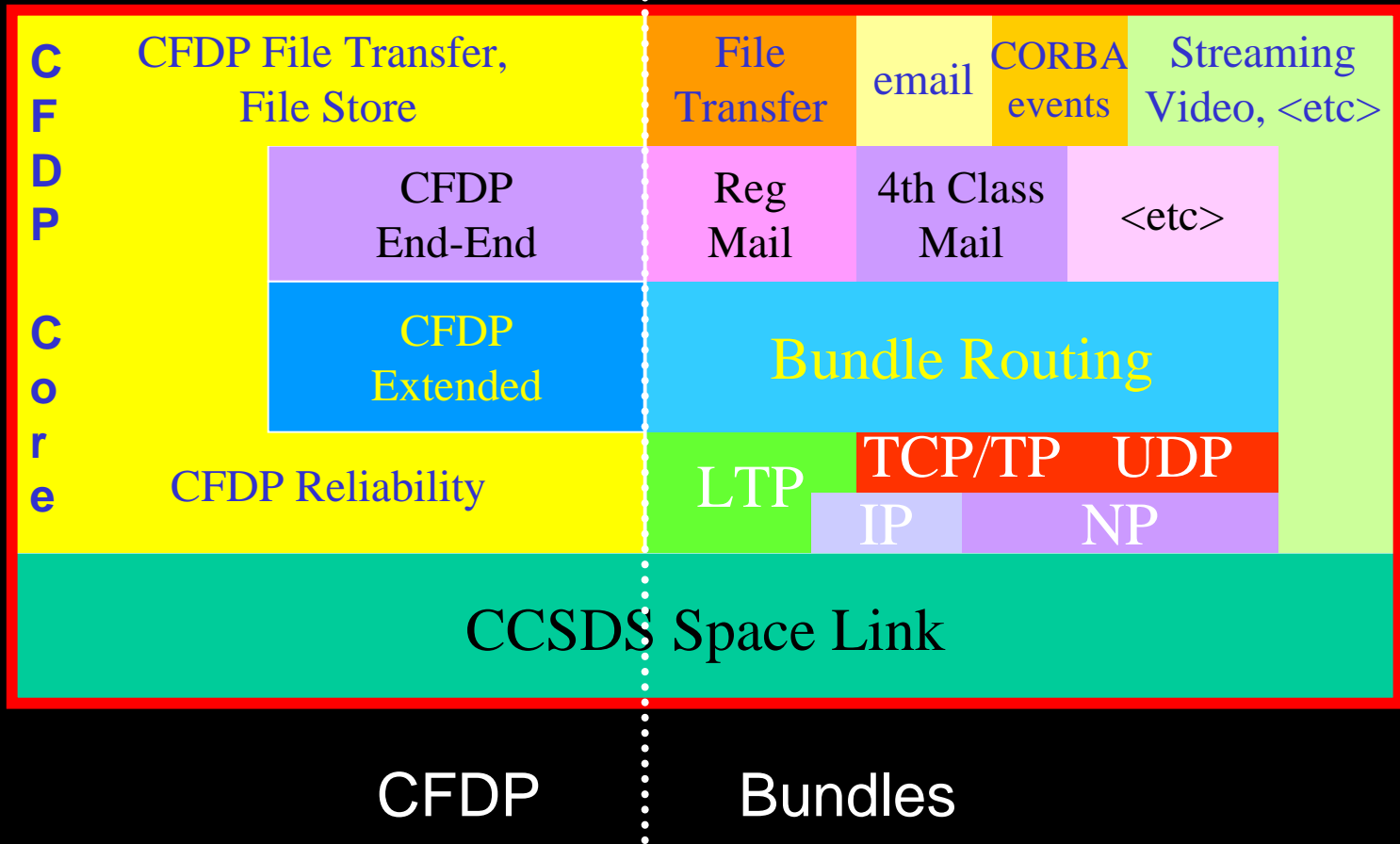
** Security, if desired, lives in the purple stuff*



Networked CCSDS Space/Ground Communications Protocol Stack



Bundling and CFDP



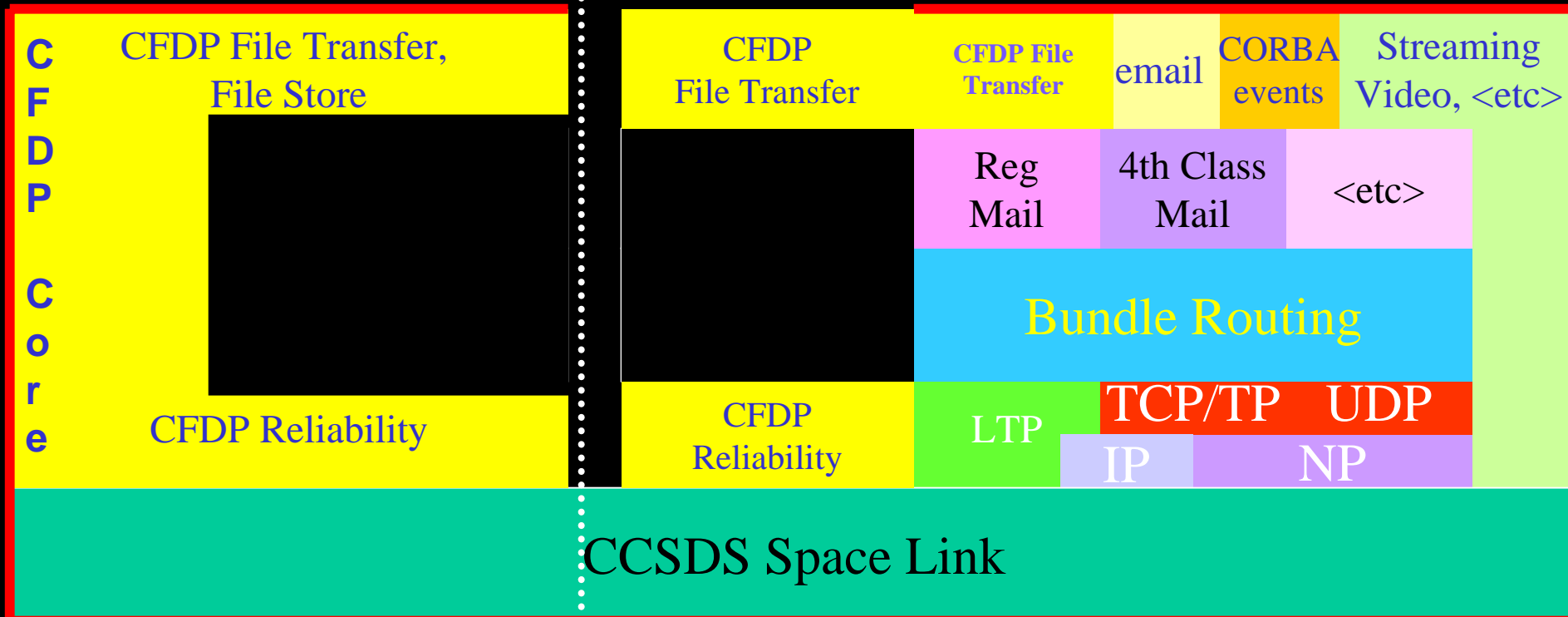
Current CCSDS Strategy:
move CFDP Core + "informative"
Extended procedures
to a Blue Book.....

.....and defer the
Extended evolution to Bundles

"CFDP Build 1"

"CFDP Build 2"

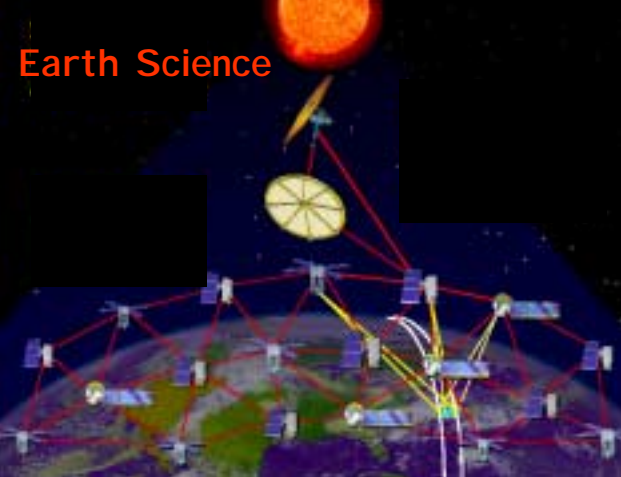
"Bundles Build 1"



CFDP

Bundles

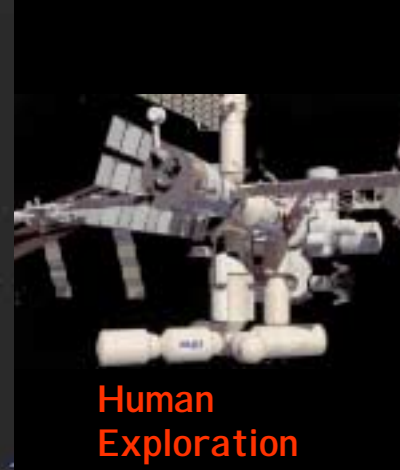
The IPN rollout has begun!



Earth Science



Deep Space Science



Human
Exploration

Progressive, planned deployment of reusable communications infrastructure



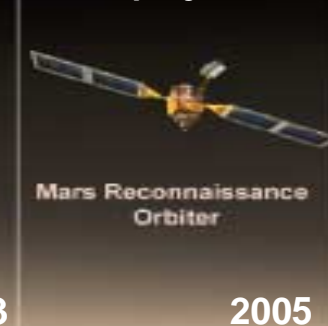
Mars Odyssey

2001



Mars Reconnaissance
Orbiter

2003



2005



ASI Telecom

CNES Aerocapture

2007



ASI/U.S. SAR

2009



2011

In-depth Planetary Exploration



Mars
Exploration
Rovers



Netlanders



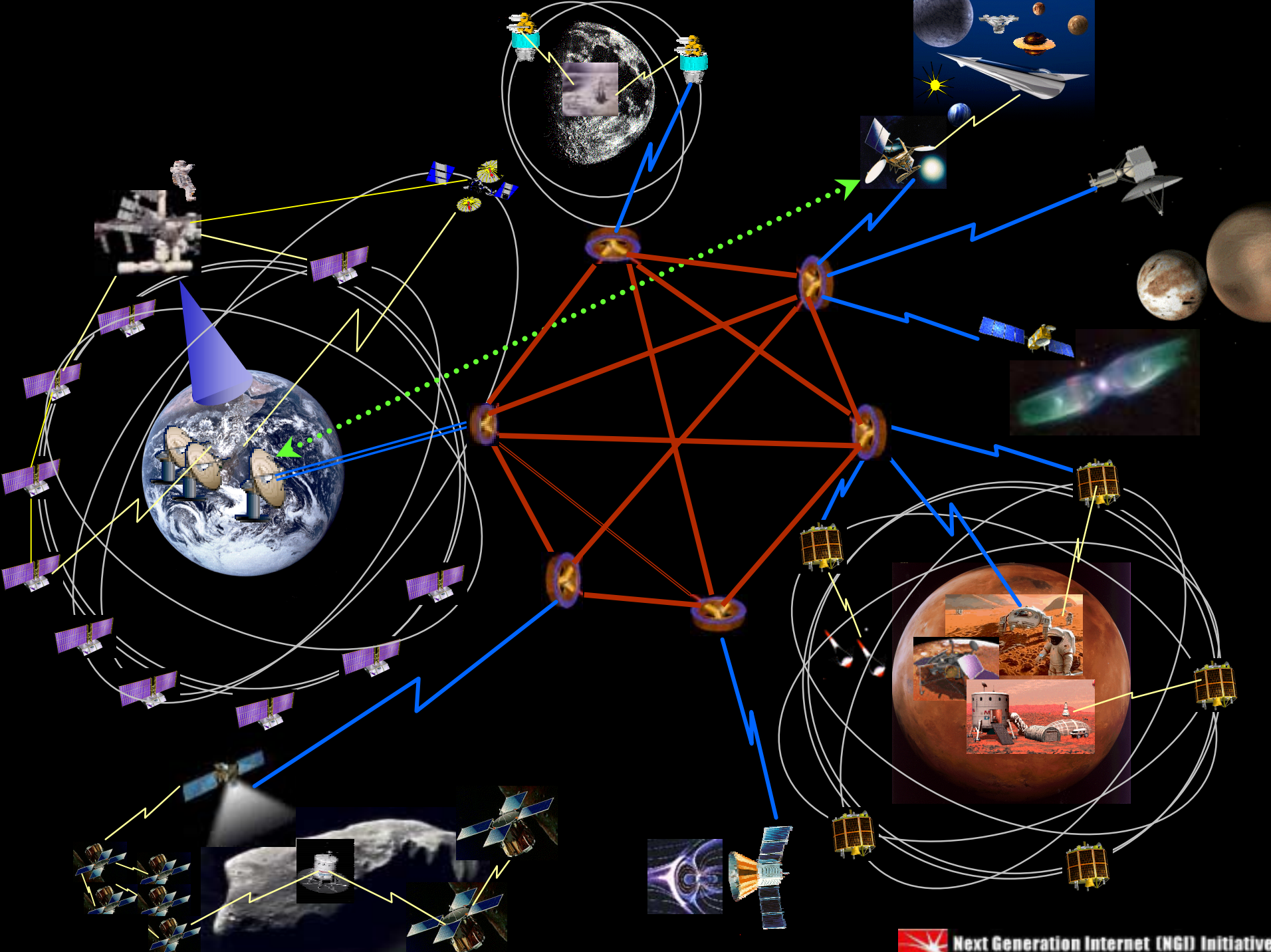
Smart Lander
& Rover



Aerial Scouts



Mars Sample Return
(with Smart Lander & Rover)



For more information.....



... <http://www.ipnsig.org>